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E. Monstvilas

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OPTIMAL INSULATION OF DISTRICT HEATING PIPELINES

E. Monstvilas

A new building code with sharper requirements for buildings and building elements in regard to energy consumption decrease was already prepared in 1991, but the requirements for insulation level of district heating pipelines have not been changed till now. There were wide discussions held considering the acceptable heat insulation level of pipelines, but a unanimous opinion on this matter has not been formed. The data of real heat losses in district heating pipelines are very different. In the opinion of some authors, the heat losses in the pipelines of district heating system can reach up to 30% of the amount of transported energy.

The majority of district heating pipelines in Lithuania are insulated according to the requirements of SNiP 2.04.14-88 [1] of the former Soviet Union. This Building Code formally has been in force up to now. The materials indicated in this Building Code have worse thermal properties than the up-to-date insulating materials on the market. Nevertheless, the thermal energy and materials prices, having a direct economical influence on the thickness of insulation, have changed significantly since 1988.

The purpose of our investigation considering the mentioned circumstances was the following: to determine the optimal thermal resistance values for various district heating pipeline types in regard to energy and financial expenditures at installation and operation of them, to define the optimal insulation thicknessess and to prepare the data forming the background criteria of requirements in the new building code.

The calculations were performed for the open space pipeline and underground pipeline types in impassable channels and without channels. The magnitude of limit heat losses in all the considered types of pipelines was estimated according to the methods indicated in Chapter 9 of [2].

The optimal solution from the point of view of energy consumption was evaluated at minimum total energy consumption in regard to thermal resistance of pipe insulation at fixed diameter and certain disposition type of considered pipeline, in (kg of reference fuel RF)/(m·year).

Annual total energy consumption C_s, (kg RF) / (m·year), is determined as the sum of energy consumption at installation of district heating pipeline C_1, and energy consumption at the operation of its C_e:

$$C_s = C_1 + C_e. \qquad (1)$$

The energy consumption at the installation of district heating pipeline C_i, (kg RF)/(m•year), is considered as follows:

$$C_1 = \left(C_{m.g.} + C_s\right) \cdot p / T; \qquad (2)$$

where

$C_{m.g.}$ - energy consumption used for production of materials (concrete channel, pipe, insulating and protective materials etc), (kg RF) /(m·year);

C_s - energy consumption used on building site of district heating pipeline, (kg RF) /(m·year);

p =1,6 - standard coefficient to evaluate the increase of value at T =8,33 year;

T - standard pay-back period for district heating pipeline, assumed to be equal 8,33 year

The annual energy consumption for operating of district heating pipeline C_e, (kg RF)/(m•year), is estimated as follows:

$$C_e = C_{n.a.} + C_t + C_{v.n.} \qquad (3)$$

where

$C_{n.a.}$ - annual energy losses to the environment through the insulation of pipeline and other constructions, (kg RF)/ (m·year);

C_t - annual energy losses due to transporting energy agent, (kg RF) /(m·year);

$C_{v.n.}$ - annual energy losses due to the water leakage in district heating pipelines, (kg RF) /(m·year);

The calculations of optimal insulation level have been determined in two ways:

1. By the estimation of energy consumption only,
2. By the estimation of economical situation, that is, evaluating energy, labour and material prices.

1. Calculations of optimal insulation estimating energy consumption

First, calculations have been performed to evaluate energy consumption only, without considering the energy, labour and materials prices. The following energy consumption components have been considered for the determination of optimal thermal resistance of the pipelines:

- energy consumption due to the installation of the pipeline;
- energy consumption due to the operation of the pipeline;
- total energy consumption, as the sum of the energy consumption due to the installation and operation of the pipeline.

Optimal thermal resistances have been determined according to minimal value of total energy consumption by a graphic way. In Fig 1 an example of calculation results for the pipeline of 150 diameter in the impassable channel is presented.

In both cases the optimal thermal resistance is close to 2,5 (m·K)/W according to the presented calculation results.

However, in our opinion, the calculations according to the energy consumption only are more complicated as the economical ones. The reason is in precise determination, which is quite intricated because:

- energy consumption depends on the technology of manufacturing and effected by a lot of other factors there,
- it is difficult to get sufficient information from the manufacturers.

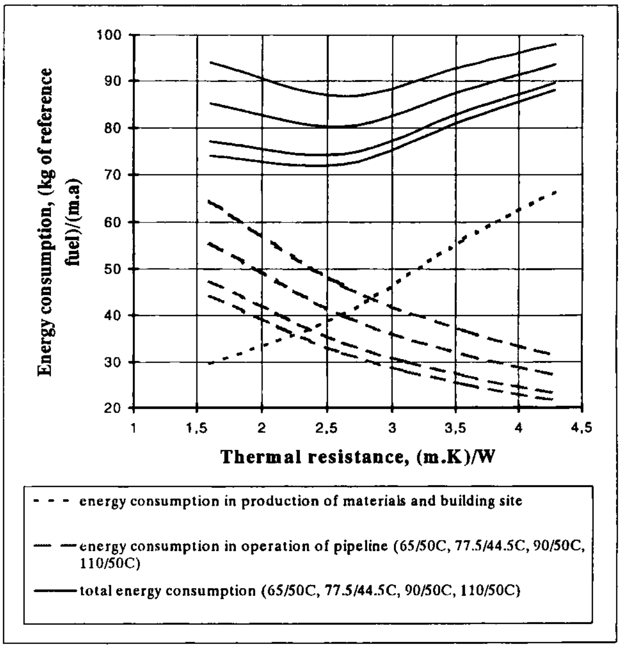

Fig 1. Optimal thermal resistance for the pipeline of 150 mm diameter in the impassable channel according to the results of energy consumption calculation. In the brackets the design supply and return temperatures of energy agent are indicated

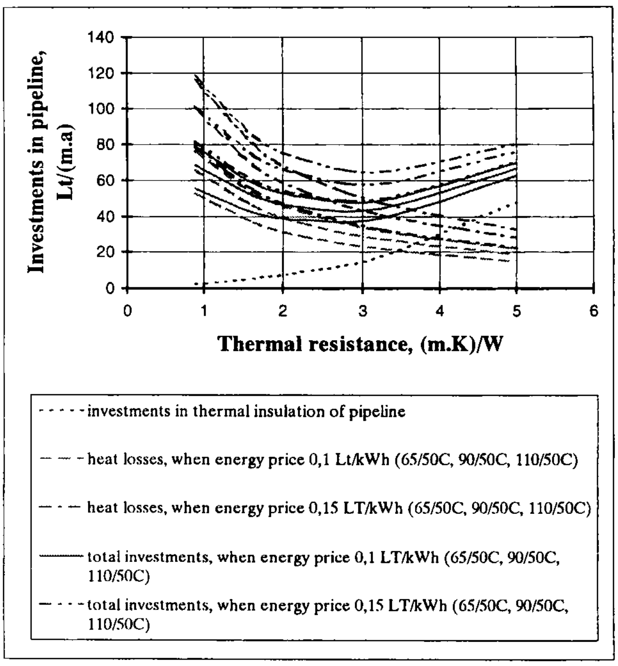

Fig 2. Optimal thermal resistance for the pipeline of 150 mm diameter in the impassable channel according to the results of economical calculation

Thus, at the stable economical situation in the country, in our opinion, the economical calculation results are more reliable.

It is worth noting that the results of optimal thermal resistance calculation estimating energy consumption only are very close to the determined ones considering all economical compounds. The results of economical calculation for the same case as in Fig 1 are presented in Fig 2 to prove this statement.

2. Economical calculations of optimal insulation for district heating pipeline

The economical calculations of optimal insulation for district heating pipelines were performed in the second stage of the investigation. Some of the initial data and calculation results for open space pipelines, for pipeline types in underground impassable channels and underground without channels are discussed in the material below.

2.1. Open space pipelines

For economical calculations, the data presented by "PAROC SILIKATAS" mineral wool factory have been used. The calculations have been performed for two cases:

1. Insulating material - mineral wool technical insulation mats

- heat conductivity coefficient 0,04 W/(m.K);
- density 35-100 kg/m^3 ;
- price 420-540 Lt/ m^3, that is, average price near 480 Lt/ m^3 ;

It is assumed that the labour expenditures for insulation of 1 m pipeline on the building site exceed the 15% of the insulation material cost.

2. Insulating material - mineral wool prefabricated technical insulation shells

- heat conductivity coefficient 0,04 W/(m·K);
- density 100 kg/m^3 ;
- price 1000-1300 Lt/ m^3, that is, average price near 1150 Lt/ m^3 ;

It is assumed that the labour expenditures for insulation of 1 m pipeline on the building site exceed the 10 % of the insulation material cost.

The calculations have been performed for diameters of 20, 70, 150, 300, 600 and 1000 mm open space pipeline. For every diameter of the considered type of pipeline the optimal value of insulation thermal resistance has been determined according to the curves adequate to the presented ones in Fig 2. The data have been used for the determination of optimal thermal resistance dependence due to the diameter of open space pipeline. The dependence is presented in Fig 3. It can be noted that the required value is higher when the insulating shells are used instead of insulating mats. The reason is the difference of prices, the prefabricated shells are almost twice expensive than mats.

The calculation results according to the graphs in the Fig 3, when the technical mats are used for open space pipeline insulation, have been put in the background of the standard requirement. The limit heat losses of the pipeline and requirement for the minimum insulation thickness have been obtained from those data (Fig 4).

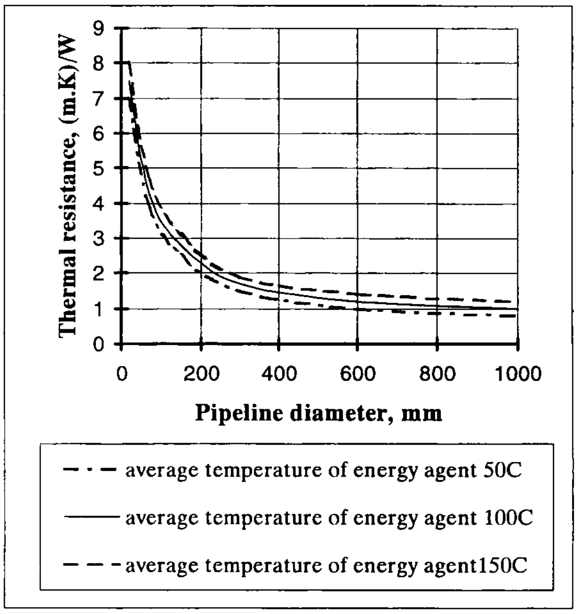

Fig 3. Thermal resistance dependence of insulation due to diameter of open space pipeline, when the diameter is between 20 to 1000 mm. Insulating material - mineral wool insulating mats with density 35-100 kg/m^3 , average price of 480 Lt/m^3 . Energy price 0,1 Lt/kWh

2.2. Underground pipelines without channels

For the calculation the following data from JSC "KAUNO ENERGIJA" pipe insulation factory have been used:

- insulating material - polyurethane foam;
- heat conductivity coefficient 0,031 W/(m.K);
- density 60-80 kg/m^3 ;
- average price near 860 Lt/ m^3 ;

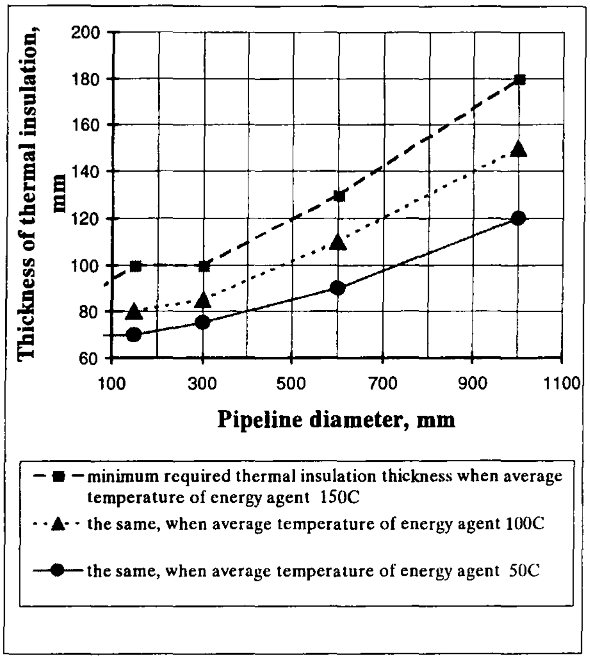

Fig 4. Optimal thickness of open space pipeline insulation when design thermal conductivity coefficient is 0,04 W/(m·K), energy price 0,1 Lt/kWh

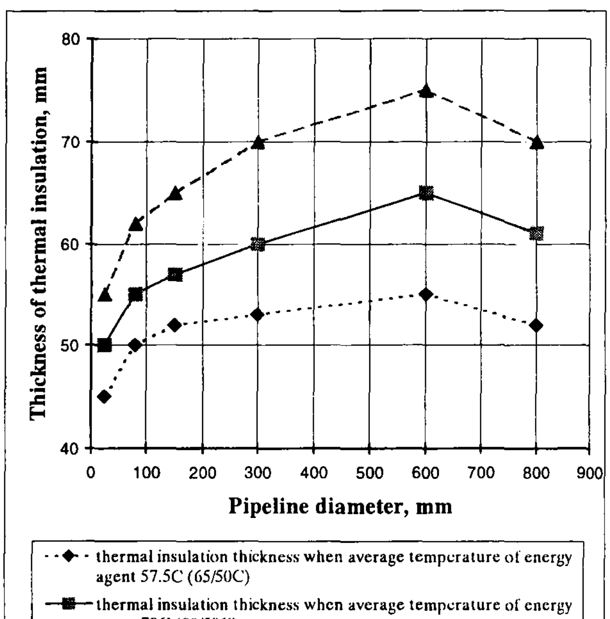

Fig 5. Optimal insulation thickness for underground pipeline without channel when design thermal conductivity coefficient is 0,031 W/(m·K), energy price 0,1 Lt/kWh

It is assumed that the labour expenditures for insulation of 1 m pipeline on the building site exceed the 10% of the insulation material cost.

The calculations have been performed for pipeline diameters of 25, 80, 150, 300, 600 and 800 mm. The calculation order was the same as in the case of open space pipeline. According to the obtained results, the dependence of optimal thickness due to pipeline diameter for underground pipeline type without channel is established (Fig 5).

Comparison of the results for the calculation according to the total energy consumption for the pipeline and economical calculation demonstrate good accordance at small diameter sizes (at 150 mm diameter the optimal thermal resistance value is 2,5-3, (m·K)/W), but the difference is more significant at large diameters. The value of optimal thermal resistance obtained by the calculation of energy consumption only is higher than found by another way. If the results of calculation by energy consumption could be taken into consideration as more reliable, then the results of economical calculation, and less strict requirements for pipeline insulation at the same time, indicate that, perhaps, energy price is too low, or the price of polyurethane foam used for insulation of underground pipeline without channel is too high for Lithuanian economical conditions.

Furthermore, after recalculation at energy price of 0,15 Lt/kWh, the comparison of results in both cases show close optimal thermal resistances.

2.3. Pipelines in impassable underground channels

For economical calculations, the data presented by "PAROC SILIKATAS" mineral wool factory have been used. The calculation has been performed in two cases:

1. Insulating material - mineral wool technical insulation mats
   - heat conductivity coefficient 0,04 W/(m.K);
   - density 35-100 kg/m^3;
   - price 420-540 Lt/ m^3, that is, average price near 480 Lt/ m^3;

It is assumed that the labour expenditures for insulation of 1 m pipeline on the building site exceed the 15% of the insulation material cost.

2. Insulating material - mineral wool prefabricated technical insulation shells
   - heat conductivity coefficient 0,04 W/(m·K);
   - density 100 kg/m^3;
   - price 1000-1300 Lt/ m^3, that is, average price near 1150 Lt/ m^3;

It is assumed that the labour expenditures for insulation of 1 m pipeline on the building site exceed the 10% of the insulation material cost. The calculation order was the same as in the case of open space and underground without channel pipeline types. The calculations have been performed for pipeline diameters of 25, 70, 150, 300, 600, 900 and 1400 mm.

The optimal thermal resistance dependencies obtained for various temperatures of energy agent due to diameter of the pipeline are presented in Fig 6.

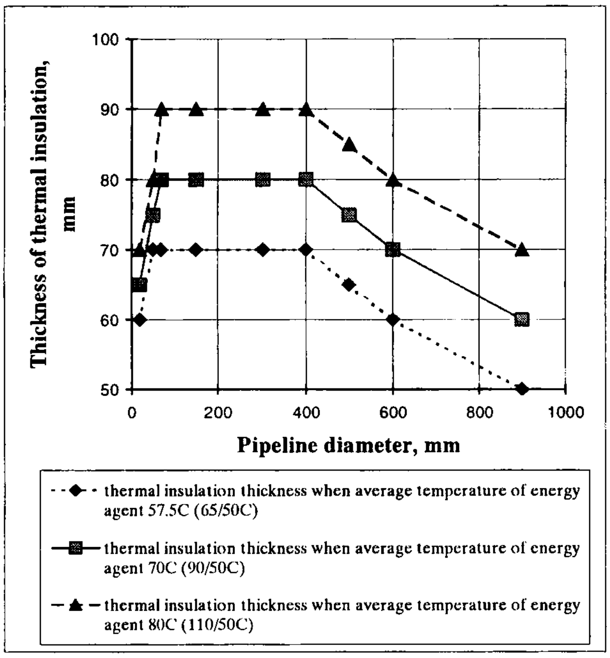

Fig 6. The optimal insulation thickness of underground pipeline in impassable channel when design thermal conductivity coefficient is 0,04 W/(m·K), energy price 0,1 Lt/kWh

The optimal thickness of this type of pipeline is very close estimating by both methods of calculation at small diameter of pipeline. Optimal thickness is 2,0-2,5 (m·K)/W for 150 mm diameter, for example. When the diameters are large, the difference could be seen at applying economical calculations and estimating to energy consumption only. Calculation estimating energy consumption shows larger thermal pipeline resistance required as compared with economical calculations. The results considered are very similar to those obtained for underground pipeline type without channel.

The same conclusion about the use of prefabricated shells could be obtained as in the case of open space pipelines. It depends on the higher level of prefabricated shells.

3. Additional discussion of obtained results

The data presented in Fig 5 and 6 show the trend that the optimal insulation thickness would decrease (at diameters larger than 400 mm). But in neighbouring north countries, as Finland [3] or Sweden [4], the required insulation thickness value is not decreased with the increase of diameter. This regularity in our calculation results is stipulated by inadequacy in energy price with the prices of insulating materials. So the additional calculation have been performed at the energy prices of 0,3 Lt/kWh and 0,45 Lt/kWh, the price of insulating material has been fixed at 480 Lt/m^3. The results of this calculation are presented in Fig 7. It seems that with the increase of energy prices the regularity considered (in comparison with data in Fig 6) for large diameter of pipeline is slowly disappearing. The similar picture for the regularity discussed is obtained when the prices of insulating materials are decreased and the energy price is fixed.

At the prices of energy and insulating materials of today situation it is economically profitable to insulate pipelines of large diameter (400 mm and more) with the thickness larger than presented in Fig 6, only with cheap insulating materials.

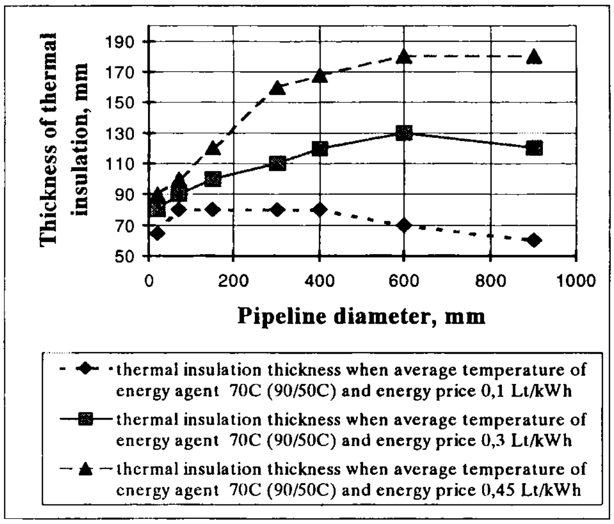

Fig 7. Optimal insulation thickness at different energy prices for underground pipeline type in impassable channel. Price of insulating materials is fixed at 480 Lt/m^3, design thermal conductivity coefficient is 0,04 W/(m·K)

The results of investigation, funded by Ministry of Economy of Lithuania, are discussed in this report. The coordinator of investigation is Energy Strategy

Section of Energy Development Department at Ministry of Economy.

Conclusions

1. The optimal insulation thickness in regard to the diameter of pipeline applied for open space pipelines should correspond to values presented in Fig 4. The required heat losses should be decreased from 1,2 up to 1,7 times in regard to pipeline diameter and average temperature of energy agent if compared with requirements of SNiP 2.04.14-88 [1], which are in force now.

2. The optimal insulation thickness in regard to the diameter of pipeline applied for underground pipelines without channel should correspond to values presented in Fig 5. The required heat losses should be decreased from 1,2 up to 1,8 times in regard to pipeline diameter and average temperature of energy agent if compared with requirements of SNiP 2.04.14-88 [1].

3. The optimal insulation thickness in regard with the diameter of pipeline applied for underground pipelines in impassable channels should correspond to values presented in Fig 6. The required heat losses should be decreased up to 1,7 if compared with requirements of SNiP 2.04.14-88 [1].

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OPTIMALUS ŠILUMINIŲ TRASŲ APŠILTINIMAS

E. Monstvilas

S a n t r a u k a

Daugelis Lietuvoje esančių šilumos tiekimo tinklų sumontuoti pagal 1988 m. normas SNiP 2.04.14-88 [1]. Formaliai šios normos galioja ir dabar. Jose minimos šilumos izoliuojamosios medžiagos yra gerokai blogesnių savybių, negu naudojamos dabar. Be to, nuo 1998 m. pasikeitė šiluminės energijos ir medžiagų kainos, kurios tiesiogiai veikia ekonomiškai tikslingą izoliacijos storį.

Todėl tyrimų tikslas buvo šis: įvertinant šilumos tiekimo trasų įrengimo ir eksploatacijos energijos ir finansines sąnaudas, nustatyti įvairių tipų trasų optimalias vamzdynų apšiltinimo šilumines varžas, apskaičiuoti optimalius apšiltinimo storius ir parengti duomenis naujoms normoms sudaryti.

Apskaičiavimai buvo atliekami įvairaus skersmens antžeminėms, bekanalėms ir kanalinėms šilumos tiekimo trasoms. Visų šių trasų šilumos nuostoliai į aplinką buvo apskaičiuoti pagal literatūros [2] skyriuje 9 pateiktas metodikas.

Esant fiksuotam trasos vamzdynų skersmeniui, tam tikro trasos paklojimo būdo optimalus energetiniu požiūriu sprendimas buvo nustatomas fiksuojant minimalias sumines energijos sąnaudas priklausomai nuo trasos vamzdynų šiluminės izoliacijos šiluminės varžos.

Vamzdynų optimalaus šiltinimo apskaičiavimai buvo atliekami dviem būdais:

1. Įvertinant tik energijos sąnaudas.
2. Įvertinant ekonominius rodiklius, t.y. įvertinant energijos, darbo ir medžiagų kainas.

Pirmajame tyrimų etape skaičiuota pagal energijos sąnaudas. Buvo įvertinamos tik energijos sąnaudos ir neįvertinama energijos, darbo bei medžiagų kaina. Nustatant optimalias vamzdynų apšiltinimo šilumines varžas buvo įvertinamos energijos sąnaudos:

- trasai įrengti;
- eksploatuoti;
- bendrosios sąnaudos, t.y. energijos sąnaudų suma trasai įrengti ir eksploatuoti.

Optimalios šiluminės varžos buvo nustatomos grafiniu būdu pagal minimalias bendrąsias energijos sąnaudas.

Autoriaus nuomone, skaičiavimai pagal energijos sąnaudas yra daug sudėtingesni ir mažiau tikslūs negu skaičiavimai pagal ekonominius rodiklius. Todėl, esant pakankamai stabiliai ekonominei situacijai rinkoje, reiktų labiau pasitikėti skaičiavimais pagal ekonominius rodiklius.

Antrajame tyrimų etape buvo atlikti vamzdynų optimalaus apšiltinimo apskaičiavimai įvertinant ekonominius rodiklius. Apskaičiavimų rezultatai apie įvairaus tipo šilumos tiekimo trasų apšiltinimo optimalius storius pateikiami 4, 5, 6 pav.

Sulyginus 5 ir 6 paveiksluose pateiktus duomenis nustatyta, kad didelio skersmens vamzdynų, didėjant jų skersmeniui (daugiau kaip 400 mm), mažėja optimalus šiluminės izoliacijos storis. Analogiški normų duomenys Suomijoje [4] ir Danijoje [5] rodo, kad didėjant skersmeniui, izoliacijos storis neturėtų mažėti. Šį mūsų nustatytą dėsningumą lemia maža energijos arba didelė šilumos izoliuojamųjų medžiagų kaina. Todėl kanalinių trasų vamzdynams buvo atlikti papildomi apskaičiavimai, kuriuose energijos kaina padidinta iki 0,3 Lt/kWh ir iki 0,45 Lt/kWh, o šilumos izoliuojamosios medžiagos kaina buvo fiksuota ir lygi 480 Lt/ m^3. Šių apskaičiavimų duomenys pateikti 7 pav. Jie rodo, kad aukščiau nustatytas dėsningumas (6 pav.), kai didesnio kaip 400 mm skersmens vamzdynų izoliacijos storiai yra mažesni palyginti su mažesnio skersmens vamzdynų apšiltinimo izoliacijos storiais, didinant energijos kainą po truputį išnyksta. Analogiški rezultatai gaunami ir mažinant šilumos izoliuojamosios medžiagos kainą, kai energijos kaina yra fiksuota. Todėl, esant dabartinėms energijos ir šilumos izoliuojamųjų medžiagų kainoms, apšiltinti didelio skersmens vamzdynus didesnio negu pateikta (6 pav.) storio izoliacija ekonomiškai tikslinga tik naudojant pigesnes šilumos izoliuojamąsias medžiagas.

Šiame straipsnyje pateikti tyrimų rezultatai buvo gauti atlikus Lietuvos Respublikos ūkio ministerijos finansuojamus darbus. Šių darbų koordinatorius – Lietuvos Respublikos ūkio ministerijos Energetikos vystymo departamento Energetikos strategijos skyrius.

Išvados

1. Antžeminių trasų vamzdynų apšiltinimo optimalūs storiai priklausomai nuo izoliuojamo vamzdžio skersmens turėtų atitikti 4 pav. pateiktus duomenis. Palyginti su dabar naudojamo normatyvo SNiP 2.04.14-88 [1] norminiais šilumos nuostoliais, šiuos šilumos nuostolius reikėtų mažinti nuo 1,2 iki 1,7 karto atsižvelgiant į vamzdžio skersmens ir šildalo vidutinę temperatūrą.

2. Bekanalių trasų vamzdynų apšiltinimo optimalūs storiai atsižvelgiant į izoliuojamo vamzdžio skersmenį turėtų atitikti 5 pav. pateiktus duomenis. Palyginti su SNiP 2.04.14-88 [1] norminiais šilumos nuostoliais, šiuos šilumos nuostolius reikėtų mažinti nuo 1,2 iki 1,8 karto atsižvelgiant į vamzdžio skersmenį ir šildalo vidutinę temperatūrą.

3. Nepraeinamuose kanaluose esančių šilumos tinklų vamzdynų apšiltinimo optimalūs storiai, atsižvelgiant į izoliuojamo vamzdžio skersmenį, turėtų atitikti (6 pav.) pateiktus duomenis. Palyginti su SNiP 2.04.14-88 [2] norminiais šilumos nuostoliais, šiuos šilumos nuostolius reikėtų mažinti apie 1,7 karto.

Edmundas MONSTVILAS. Doctor. Institute of Architecture and Construction, Building Physics Laboratory. Tunelio 60, 3035 Kaunas, Lithuania.

Participant of research projects from 1977. Doctor (technical sciences), 1982. Author of more than 30 projects, more 20 reports and papers. Coauthor of Lithuanian Building Codes and Regulations: RSN 117-89 "Directives for sealing of assembled construction joints by polyurethane foam Ripor 6TN-1", VST 25898-83 "Building materials and products. Vapour resistance determination method", RSN 143-92 "Building Thermal Technique". In 1996-97 participant of the work group of a new edition of Building Code "Building Thermal Technique". Manager of a work group for arranging a new Building Code "Rules for Determination of Laboratory, Declared and Design Values of Thermal-Technical Characteristics for Building materials and Products". In 1997 manager of the work group for compiling a new Building Code "Thermal Insulation of Pipelines".