METHODOLOGY FOR CALCULATION OF PRE-INSULATED PIPING SYSTEMS FOR HEAT SUPPLY

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Abstract: *The article presents own four stage methodology for calculating stresses and elongations in Pre-insulated Pipe Systems (PiPS) for heat transmission networks, taking into account the changes in diameter in the considered section. The application of this methodology leads to systematization and automation of data processing related to PiPS, which reduces the effort and costs required for the design and ensures compliance with the conditions for maximum load. The developed approach can be used to build an Information System based on Software Design Patterns.*

Keywords: *Software Engineering, Heat Supply, Software Design Patterns*

1. Introduction and description of Pre-insulated pipe systems

Pre-insulated pipe systems (PiPS) are widely used in the heat transmission industry via the heat transmission network [BDS EN 253:2020], [BDS EN 489-1:2020]. Their specific construction (complete with steel service pipe, polyurethane thermal insulation and outer shell of polyethylene) allows the transport of fluids with high operating temperatures and high pressures, witch their service life is up to 30 years and ensures up to 70% less heat losses.

PiPS is dug directly into the ground and their design and installation is applied according to the standard [BDS EN 13941 + A1], [LOGSTOR]. For analysis and sizing, the system of pipes is divided into participants: part of the pipeline, concluded between two compensa-ting elements (elbows) - **Figure 1.**

A section is considered, which is composed of pipelines with different diameters and different friction area of the casing with the sand cushion. The change in diameters is taken into account, which provides a more accurate calculation of the stresses and elongations of the pipeline. The calculate the maximum stress σmax for a section of the heat pipe, which is a function of the pipe diameter, the friction force, the difference in temperature and the length of the pipe. For the section considered in **Figure 1**, the maximum compressive stress must be less than the allowable ($\sigma max < \sigma all$). The linear elongation ΔL of a steel pipe laid without preheating in a trench is determined by the friction force, the length and cross-sectional area of the steel pipe and the difference between their operating and installation temperatures.

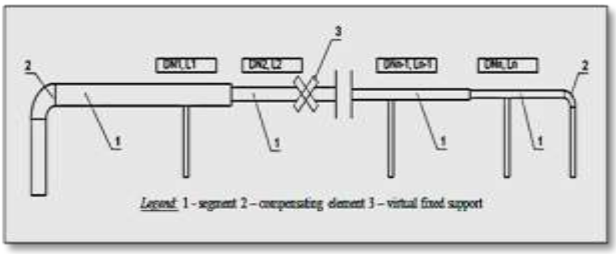

Figure 1: *Visualization of a section with specified pipe diameter and length*

2. Review

2.1 Advantages

Advantages of using PiPS instead of traditional insulation in systems provide: 100 percent watertight and corrosion protected; energy saving (i.e. low heat loss, more energy-efficient of traditionally insulated pipes); no maintenance costs; UV resistant; increased surface strength; low emissions. [LOGSTOR]

2.2 Manufacturers

Some of the major manufacturers of PiPS are: Uponor Corporation, KE KELIT Austria, KC Polymers Pvt Ltd., GF Piping Systems, Ecoline S.R.L., LOGSTOR A/S and others (asper Transparency Market Research).

2.3 Methodologies and approaches used in practice

The scientific interest in PiPS is focused on the development of various methodologies, approaches and methods related to:

- determining the service life of the pipeline (A new and highly sensitive method for regular inspection (ILI) for gas pipelines, which is based on integrated methods for ILI, optical sensor and bimorph sensor [Sampath,2020]);

- *Emission reduction* - develop plans to decarbonise the transport and energy sectors [KLEPERIS,2021];

- *Determining the efficiency in extreme conditions* - determining the effectiveness of the methods in extremely dry and salty conditions in view of the electrical and geological shielding [HAMMOUD,2021];

- *Evaluation of defects* - a comprehensive review of the principles, numerical solutions, and applications of Levels 1, 2 and 3 defect assessment methods developed in the past four decades [Guojin,2021].

2.4 Software solutions

There are a number of software solutions for designing pipe systems: Fluid Dynamic Simulation Software (AFT Fathom); sisKMR Software - Static calculation of pre-insulated pipe systems (above and below ground) [CPV]; The program for sizing pipes and calculating heat loss.[LOGSTOR] and other.

3. Four stages methodology for sizing pipelines

One of the most common problems is related to the calculation of stresses and elongations in PiPS for heat supply. The process of calculating and processing data related to PiPS is a labor-intensive activity and requires time and effort on the part of the designer. To automate this data processing and reduce design efforts, the authors propose a four stages methodology.

The developed methodology, in contrast to the existing ones, takes into account the change in diameters for a specific section.

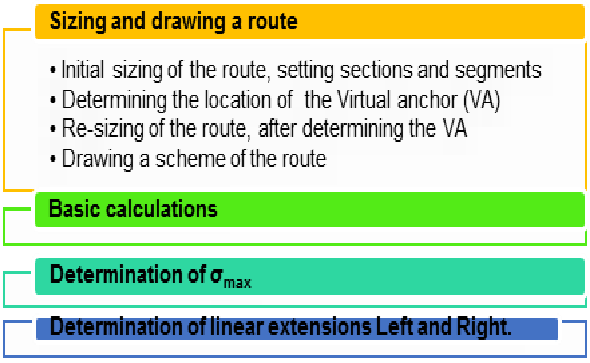

Figure 2: *Four stages in sizing of PiPS*

3.1 Sizing and drawing a route

3.1.1 Initial sizing of the route

- Route selection
- Dividing the route into p sections

  REPEAT
- Registration of section S [i]

  REPEAT
- Registration of Pipes segment [i, num] in section S [i]
- Setting the pipe length L [i, num] from Pipes segment [i, num]
- Setting the pipe diameter DN [i, num] from the Pipes segment [i, num]
- Calculation of $\frac{1}{2} * \mathrm{SumL}[i, num]$

  WHILE num <= q

    WHILE i <= p

i is a sequence number of a section, i ϵ [1; p]
p is the total number of sections
num is a sequence number of a segment in a section, num ϵ [1; q]

q is the total number of segments in section S [i], such as $q_{max} = 6$

$\frac{1}{2} * \mathrm{SumL[i, num]}$ is ½ the sum of the lengths of q number of pipes laid in series in the q segment, in section S [i]

$$\frac{1}{2} * \mathrm{SumL[i, num]} = \frac{1}{2} * (\mathrm{L[i, 1]} + \cdots + \mathrm{[i, 2]} + \mathrm{L[i, q]}) \quad (1)$$

3.1.2 *Determining the location of the VA*

FOR (i=1; i<=p; i++)

FOR (num=1; num<=q; num++)

- Calculation of SumLVA [i, num]
- Comparison of SumLVA [i, num] and $\frac{1}{2} * \mathrm{SumL[i, num]}$

- *IF* $\mathrm{SumL_{VA}}$ [i, num] > $\frac{1}{2} * \mathrm{SumL[i, num]}$,
  THEN VA[i, num]=num
- *ELSE* move to item 1.
- **$\mathrm{SumL_{VA}}$ [i, num]** is the sum of the lengths of the tubes, to the location of the VA, in a segment Pipes (i, num])

VA [i, num] is the VA number in the segment Pipies[i, num]

$$\mathrm{SumL_{VA}}\,[i, num] = \mathrm{SumL_{VA}}\,[i, num] + L[i, num] \quad (2)$$

3.1.3 *Re-sizing of a section of the route, after determining the VA*

After determining the VA, each section is divided into three zones. Zone 1 includes segments located to the left of the split segment, zone 2 is the zone with the split segment (i.e. the segment in which the VA is defined) and zone 3 is located the segments to the right of the split segment. Each segment, regardless of the area in which it is located, is resized, and the corresponding dimensions are adjusted for the length and diameter of the pipe located in the specific segment. Adjustments are made as follows:

- For a section whose segments are located on the left without the "split" segment

- The new pipe dimensions for length and diameter are:

FOR (num=1; num<=VA-1; num++)

$$\text{Length } LL[i, num] = L[i, num] \quad (3)$$

$$\text{Diameter } DNL[i, num] = DN[i, num] \quad (4)$$

- For a section whose segment is the "split" segment, its left part to the left of VA

- Calculate the SumLL [i, num] sum of the segments (i.e. the lengths of the pipes) to VA without left division:

FOR (num=1; num<=VA; num++)

$$SumLL[i, num] = LL[i, 1]+LL[i, 2]+ \ldots +LL[i, num] \quad (5)$$

- Calculation of pipe length and diameter:

$$\text{Length } LL[i, VA]) = \frac{\mathrm{SumL[i, num]}}{2} \quad (6)$$

$$\text{Diameter } DNL[i, VA] = DN[i, VA] \quad (7)$$

SumLL[i, num] is the sum of the segments to the fixed support without divisions, where num ϵ [1; VA]
LL[i, 1]….LL[i, num] are the corresponding pipe lengths

- For a section whose segments are located on the right without the "split" segment

- Calculation of pipe length and diameter

FOR (num=1; num<=num-VA+1; num++)

$$\text{Length } LR[i, num] = L[i, num] \quad (8)$$

$$\text{Diameter } DNR[i, num]=DN[i, num] \quad (9)$$

- For a section whose segment is the "split" segment, its right side to the right of VA

- Calculation of pipe length and diameter

FOR (num= VA+1; num=VA+1; num++)

$$\text{Length } LR[i, 1]= L[i, VA+1] \quad (10)$$

$$\text{Diameter } DNR[i, 1]=DN[i, VA+1] \quad (11)$$

3.1.4 *Drawing a scheme of the route*

Print a diagram of the dimensioned route with the S [i] section and the Pipes [i, num] segment in each section.

3.2 Basic calculations

- Set γ - gravity of soil and μ - friction coefficient
- Set basic parameters for steel pipe, such as do - outer diameter, s - Wall thickness of the steel pipe and others
- Calculation of Ar - Cross section of service pipe, weight of full pipe and others

Table 1: Basic Calculations

1. Setting constants: γ, μ:			
Para meter	*Dimen sion*	*Description*	
γ	N/m^3	gravity of soil	
g	m/s^2	ground acceleration (**g**=9.81)	
ρ	kg/m^3	soil density	
μ	-	friction coefficient between sand and PE outer casing	
2. Setting parameters: DN, do, s, Dc, P, V, L, H			
Para meter	*Dimen sion*	*Description*	
DN	-	Nominal pipe diameter	
do	mm	Outside diameter of steel pipe	
s	mm	Steel pipe wall thickness - according to minimum standard requirements according to BDS EN 253	
Dc	mm	Diameter of casing	
P	kg/m	The amount of water Standard pipe length Soil cover	
V	l/m	The amount of water	
L	m	Standard pipe length	
H	m	depth from ground surface to center of pipe (Soil cover)	
3. Apply formulas: Ar, G, Ffr, σ_{all}, Lmax			
Para meter	*Dimen sion*	*Description*	*Formula*
γ	N/m^3	gravity of soil	γ=ρ*g, g=9.81
Ar	m^2	Cross section of service pipe	$Ar=3.14/4*((do/1000)^2-((do-2*s)/1000)^2)$
G	N/m	Weight of water-filed pre-insulated pipe	G=(P+V)*9.81
Ffr	N/m	Friction force per unit length of pipe	$Ffr = \gamma*(0.0825*\mu*H*3.14*Dc/1000+G-1800*3.14*(Dc/2/1000)^2)$
σ_{all}	MPa	Maximum axial stress level	σ_{all} =Re/ H where Re - yield stress for steel P235GH Re=235 MPa
Lmax	m	Maximum mounting length	Lmax= σ_{all}*Ar*1000000/Ffr

3.3 Determination of σ_{max}

- Implementation of stages 1
- Setting: E - modulus of elasticity, Δt - difference between operating and installation temperature, α - coefficient of thermal expansion of steel
- Calculation of FfrLL, total products of the friction force and the length of the pipe on the left side of the section
- Calculation of σmax, maximum value of compressive stress in steel pipe in VA

Comparison of σ_{max} and σ_{all}, i.e. maximum value of pressure in steel pipe in VA and allowable pressure in steel pipe

Table 2: Determination of the Maximum Value of Pressure Stress in a Steel Pipe in VA

1. Implementation of Stages 1			
2. Setting constants: E, Δt, α			
Para Meter	*Dimen sion*	*Description*	
E	MPa	Modulus of elasticity, 210,000 Mpa	
Δt	°C	Difference between operating and installation temperatures	
α	K^{-1}	Coefficient of thermal expansion of steel, 1.2E-05	
3. Calculation of FfrLL			
	Dimen sion	*Description*	*Formula*
FfrLL	N/m	Total products of the friction force and the length of the pipe on the left side of the section	$FfrLL=(Ffr_1* LL_1+ Ffr_2* LL_2+…+ Ffr_{VA}* LL_{VA})$
4. Calculation of σ_{max}			
σ_{max}	MPa	Maximum value of compressive stress in steel pipe in VA	$\sigma_{max}=0.5*Sum (Ffr[i,num]*L[i,num]) /Ar*10^6$
5. Comparison of σ_{max} with σ_{all}			
5.1. IF **σ_{max} >= σ_{all},** THEN a route correction or compensation method is applied **5.2.** ELSE **σ_{max} < σ_{all},** THEN the extensions for the left and right part are calculated			

3.4 Determination of linear extensions Left and Right

- Determination of linear elongation Left
  - Calculation of FfrLL, these are the sum of the products of pipe length and friction force for segments 1 to VA in section Pipes [i, num]
  - Calculation of Left, section partially retained by friction (left part of section)
- Determination of linear elongation Right
  - Calculation of FfrLR, these are summed products of pipe length and friction force for segments of 1÷ q-VA+1 in Pipes section [i, num]
  - Calculation of Right, section partially retained by friction (right part of section)

Table 3: Determination of Linear Extensions

1. Determination of linear elongation Left

1.1. Calculation of FfrLL

```
FOR (i=1; i<=p; i++)
    FOR (num=1; num<=VA; num++)
FfrLL[i, num]=(Ffr[i, num]* LL[I, num])
```

Para Meter	*Dimen sion*	*Description*	*Formula*

FfrLL	N/m	Total products of pipe length and friction force for -segments 1 to VA in section Pipes [i, num]	$FfrLL=(Ffr_1* LL_1+ Ffr_2* LL_2+\ldots+ Ffr_{VA}* LL_{VA})$
1.2. Calculation of Left			
Left	m	Section partially retained by friction (left part of section)	$Left= (\alpha* \Delta t* SumLL-(FfrLL*SumLL)/(2*E*Ar*10^6))/1000$
2. Determination of linear elongation Right			
2.1. Calculation of FfrLR			

```
FOR (i=1; i<=p; i++)
   FOR (num=1; num<=q-VA+1; num++)
FfrLR[i, num]=(Ffr[i, num]* LR[i, num])
```

Para Meter	*Dimension*	*Description*	*Formula*
FfrLR	N/m	Total products of pipe length and friction force for segments of 1 ÷ q-VA + 1 in Pipes section [i, num]	$FfrLR= (Ffr_1* LR_1+ Ffr_2* LR_2+\ldots+ Ffr_{q-VA+1} * LR_{q-VA+1})$
2.2. Calculation of Right			
Right	m	Section partially retained by friction (right side of section)	$Right= (\alpha* \Delta t* SumLR-(FfrLR*SumLR)/(2*E*Ar*10^6))/1000$

4. Conclusion and Future Progress

The article discuses Pips: benefits from their use, methodologies that are applied, cites manufacturers and software developments that support the work of designers. The article proposes a methodology developed for calculating stresses and elongations in PiPS for heat transmission networks, taking into account the change in diameters. Methodology contains four stages for sizing PiPS. For each stage, the corresponding algorithm for calculating PiPS for heat supply is indicated, indicating the main calculation formulas. The purpose of the methodology is to systematize and automate the processing of data related to PiPS, which will reduce the effort required for design.

The future efforts of the authors are aimed at creating an approach based on Design Patterns and creating an Information System. As well as expanding the functionality by adding: sizing of compensators; calculation of linear displacement in tees; sizing the number and length of foam pads; and other calculations.

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References

1. [BDS EN 13941+A1] - District heating pipes - Design and installation of thermal insulated bonded single and twin pipe systems for directly buried hot water networks.
2. [BDS EN 253:2020,2020] - District heating pipes - Bonded single pipe systems for directly buried hot water networks - Factory made pipe assembly of steel service pipe, polyurethane thermal insulation and a casing of polyethylene.
3. [BDS EN 489-1:2020,2020] - District heating pipes - Bonded single and twin pipe systems for buried hot water networks - Part 1: Joint casing assemblies and thermal insulation for hot water networks in accordance with EN 13941-1.
4. [LOGSTOR], https://www.logstor.com/catalogues-and-documentation
5. [KLEPERIS,2021] KLEPERIS, J., et al. *Analysis of the Role of the Latvian Natural Gas Network for the use of Future Energy Systems: Hydrogen from Res.* Latvian Journal of Physics and Technical Sciences, 2021, 58.3: 214-226.
6. [HAMMOUD,2021] HAMMOUD, A.M., DAKWAR, N.M., VAN OOSTENDORP, D.L. *Application of Direct Assessment Methods in Arid and Sabkha Environments.* In: CORROSION 2021. OnePetro, 2021.
7. [Sampath,2020] Sampath, S., Bhattachary, B. *Development of novel integrated in-line inspection techniques for pipeline inspection.* In: SPIE Future Sensing Technologies. November 2020.
8. [Guojin,2021] Guojin, Q., CHENG, Y.F. *A review on defect assessment of pipelines: Principles, numerical solutions, and applications.* International Journal of Pressure Vessels and Piping, 2021, 104329.
9. [CPV] CPV, https://cpv.co.uk
10. [AFT] AFT, https://www.aft.com