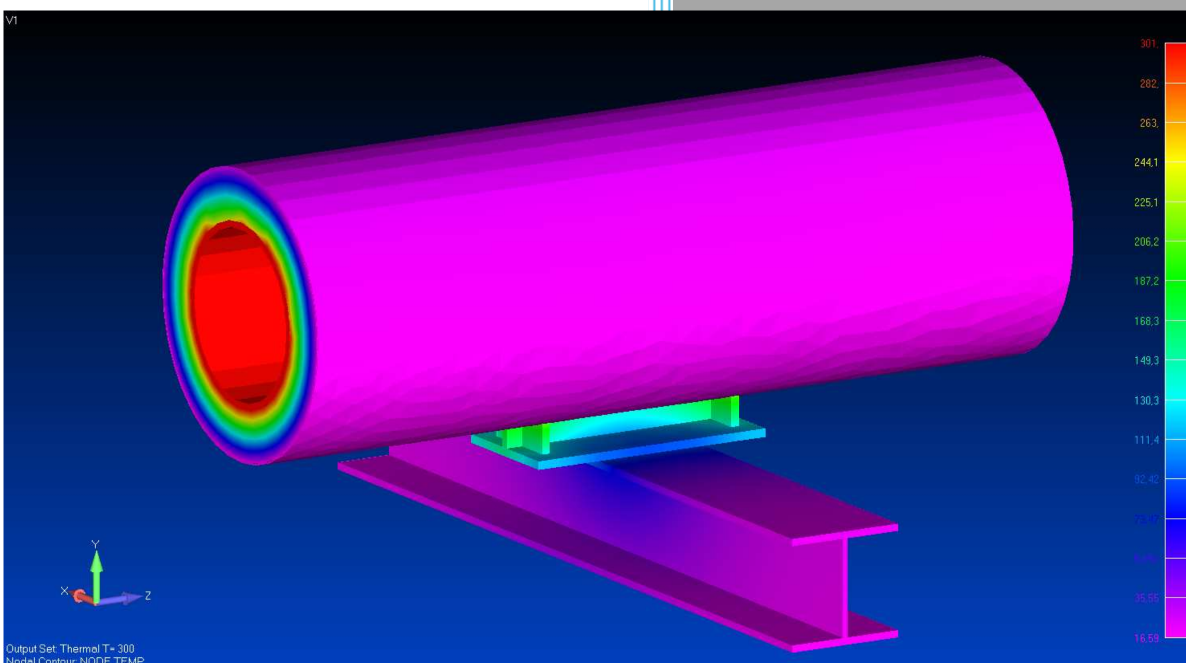
2015-2016

# Graduation thesis




# Quantifying heat loss through pipe shoe supports

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# Quantifying heat loss through pipe shoe supports


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## Foreword

I wrote this graduation thesis as part of the bachelor of applied science in mechanical engineering at The Hague University, made possible by Dosign Engineering and Jacobs Nederland BV.

The topic of heat transfer through pipe shoes came to me during measurement works for a different project. While doing site measurements near a steam line I noticed a contradicting situation. The pipe is insulated. But every 6[m] the pipe was supported on a steel pipe shoe support. The steel support forms a path where the heat can more easily escape.

I became intrigued by the question how much energy was lost and wondered about the potential savings. The savings per pipe shoe support are probably not very high but they are used often. There are at least hundreds per plant.
I discussed the problem with colleagues discovered that there is no up to date data available. I discussed this with my tutor Jaco Bergsma we agreed on the potential as a graduation assignment/project.

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# 1. Summary

The goal of the graduation thesis is to develop a method to analyze the energy losses through pipe shoe supports. The end result will be an excel file that can be used by any of the engineers within Jacobs. Therefore all calculation and fundamental data must be included. To achieve this goal the following steps have been undertaken.

## 1.1. Scope definition

The scope has been defined to cover a range of supports that fall within the common practice. The temperature range is set from 0[C] to 500[C] because this is applicable for 90% of the projects. The pipe sizes range from 4[Inch] up to and including 20[Inch] pipes, with 3 different insulation thicknesses:

- 50[mm]
- 60[mm]
- 70[mm]

Also two different solutions that reduce the heat loss will be assessed. The first is a solution that thermally separates the support from the pipe. The second thermally separates the support from the steel structure.

## 1.2. Theoretical basis

A theoretical basis is formed to understand the principals that govern the heat loss. The heat loss is approached as the sum of three sub systems:

- Heat transfer through a multi layered pipe.
- Conductive heat loss through the pipe support
- Convective heat loss through the pipe support

## 1.3. Finite element calculations

To generate accurate result finite element calculations have been performed for all support solution within the scope of work. The data is analyzed and equation are formulated that can be used to quickly assess all support solutions within the scope of this thesis.

## 1.4. Financial analysis

Due to the large scope definition a generic statement cannot be given. However the excel file created quickly generates the result required to make a finical analysis specific to the situation at hand.

## 1.5. Conclusion

Energy losses up to 900[W] per shoe are possible, for 25 supports this represents cost figures of approximately €10k per year. It is advised to further investigate the value of the thesis and economical benefits on actual and current projects.

# 2. Introduction

## 2.1. The Hague University of applied sciences

The thesis is formulated as part of the Bachelor of Mechanical engineer followed at The Hague University of Applied Science. The bachelor is a dual study program. This requires the student to work in a related field to complete the bachelor program. Two companies are involved Dosign and Jacobs. The student has been on assignment at Jacobs for 4 years and works for Dosign engineering.

## 2.2. Jacobs Engineering

Jacobs is an International engineering company providing engineering service on the global market. Jacobs operates in 14 different industrial markets ranging from Mining & minerals in Australia, Architecture & Building in Spain to Pharmaceutical in Belgium. The Netherlands operations are focused on refining & Petrochemicals.
Jacobs is focused on long term relationships. This has led to long standing service contracts with several clients and a deep understanding of their plants and systems.
The relationship with the clients has helped Jacobs to stay competitive in the local market dominated by revamp projects. The projects revolve around upgrading plants to increase the production and efficiency. In executing revamp projects, a deep understanding of the plants and processes distinguishes Jacobs from the competition.

## 2.3. Engineering in the petrochemical industry

Clients in the Dutch market operate plants build between 1960 and 1980. Due to the age of the plants much maintenance is required. Also the margins on production need to be enhanced to stay competitive in the current market. Without continuous maintenance and upgrading, the plants will become obsolete. This situation leads to lots of work for engineering companies such as Jacobs. The work entails designing improvements projects. The improvements can be made in regards of process conditions, safety, taking plants out of service and even build new plants. To realize these projects the following engineering disciplines are commonly involved Process, Instrumentation, Electrical, Civil structural and Piping design & engineering.

## 2.4. Piping design and engineering

Pipes are used to transport materials (e.g. fluid, gasses). All materials have their respective conditions that must be met to be safely and efficiently transported. To respect these conditions while creating a design is the responsibility of the piping department.
The piping department can be separated into two disciplines, into piping design and piping engineering. The design department is responsible for the translating the requirements of the stake holders in to a design. The design will be the best possible solution to the combined demands and wishes of all stake holders, including but not limited to technical requirements, operability, and maintainability while maintaining an economical design.
The Piping engineering department ensures that the design is functional and durable. Material engineers calculate if the materials selected are appropriate for the application. Examples are fluid pressure calculations and corrosion allowance calculations. Stress engineers check the piping systems to ensure the loads on the pipe and equipment are within the allowable limits. These loads include thermal expansion loads, the own weight of the pipe, the fluid transported, elements attached to the pipes and a variety of other conditions

## 2.5. Assignment

Pipes transporting hot media are insulated to reduce heat loss and maintain the required process conditions. For financial reasons soft insulation is used, for example Rockwool. These materials cannot withstand external loads. Therefore pipe supporting on insulated pipes is typically done underneath the insulation, by means of a supporting system known as pipe shoe support. This creates an un-insulated heat bridge between the pipe and supporting structure via the support shoe, as shown in figure 1.1.
Without an efficient calculation model it's too labor intensive to calculate the heat losses in projects for non-process related issues. Clients will not invest in energy conserving support solutions if the benefits cannot be provided.

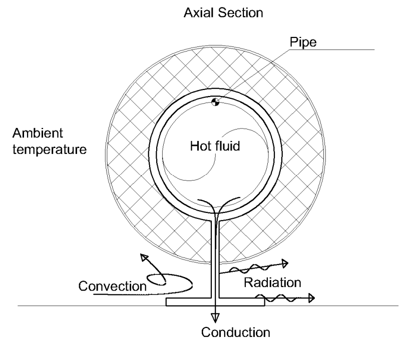


Figure 2.1: Modes of heat transfer

**The assignment:** Create an excel file that enables engineers to assess heat losses through pipe shoe supports. The excel file will include an option to simulate cases for pipe shoe supports with reduced heat loss. The excel file will generate output that provides insight in the difference between standard insulation cases and solutions with special designed insulation.

### 2.5.1. Queries

Under what conditions is it justified to invest in insulated pipe shoes?

- How much energy is lost through pipe shoes?
  - For pipe shoes on line sizes:
    - 4 [Inch]
    - 6 [Inch]
    - 8 [Inch]
    - 10 [Inch]
    - 12 [Inch]
    - 14 [Inch]
    - 16 [Inch]
    - 20 [Inch]
  - For fluids with a temperature range from 0[ºC] to 500[ºC]
  - With Rockwool insulation, thickness:
    - 50[mm]
    - 60[mm]
    - 70[mm
- What are the financial losses related to the energy losses? As per the above mentioned ranges
- What is the investment cost related to insulating solutions applied on pipe shoes? For the above mentioned range of situations.
- How much energy can be saved per insulation solution?
  - Disconnected pipe clamp
    - For pipe shoes on line sizes:
  - 4 [Inch] to 20 [Inch] For fluids with a temperature range from 0 [ºC] to 500 [ºC]
  - With Rockwool insulation, thickness:
    - 50[mm]
    - 60[mm]
    - 70[mm
- What factors determine the energy losses and to what extend?

### 2.5.2. Hypothesis

Investments in a pipe support solution that leaks less heat is profitable within in 10 years if the following conditions are true:

- The operating temperature is at least 200 [ºC]
- Cooling down of the fluid is not allowed or preferred
- Predictable investment and profit.

## 2.6. Requirements

The results of the assignment must at least meet the below specified requirements:

1. The results generated by the calculation model must be within a predicted range of accuracy per project phase:
   1.1. Select phase = 30%
   1.2. Basic design and engineering = 20%
   1.3. Detailed engineering = 10%
2. The results of the calculation must at least describe the energy loss, $CO_2$ output, and financial losses.
3. The calculation model must provide a clear overview of costs and energy losses, by means of:
   3.1. Tables
   3.2. Graphs
4. The calculation must be less time consuming than a finite element calculation.
5. The calculation must provide data ready for implementation in a heat loss quantification report.
6. The calculation program is to be made in excel to ensure all engineers and designers are familiar with the software.
7. The calculation must not be client specific.
8. The spread sheet must provide enough standard situations to construct a model accurately.
9. The work instruction must clarify the scope.
10. The work instruction must provide step by step instructions.

# 3. Orientation

## 3.1. Pipe supporting

There exists a large variety in pipe support solutions, designed for specific functions and applications. The aim of the following chapters is to clarify the difference between the existing solutions for pipe shoe supports.

A pipe shoe support is designed to separate the pipe from the supporting structure. The aim is to minimize wear on the protective coating on the pipe whilst guiding and restraining the pipe into a desired routing. When applied properly the life time of the pipe improves by reduced corrosion, designed flexibility as well as protecting possible insulation.

## 3.2. Insulation

Temperature is a key variable in the petrochemical refining industry. Some systems need to be kept on high temperature and other need to remain cold. To control and maintain the required temperature for systems insulation is used. The type of insulation used is based on the desired temperature.

## 3.3. Subdivision of piping systems based on operating temperatures

One of the process conditions that need to be controlled is the temperature. The reason for controlling the temperature is dependent on the fluid and service. For bitumen like products high temperatures are required to maintain low viscosity. Pipes transporting water need to be protected from subzero temperatures. Pipe systems can be divided in three categories bases on temperature:

- Cold systems.
- Hot systems (ambient up to 500 [ºC]).
- Hot systems (500[ºC] and above).
    - At 500 [ºC] the remaining yield strength varies between 60% and 90% of the yield strength at ambient conditions, if the temperature becomes even higher the yield strength is reduced drastically. (Chen, Young, & Uy, 2006)

Pipe system need to be supported and guided to function properly, in order to control the integrity of the system (allowable stresses). The thermal conditions of a pipe system determine the pipe supporting system to a large extend.

### 3.3.1. Cold systems

#### 3.3.1.1. *Insulation*

For systems with a temperature below ambient, cold insulation is applied to maintain refrigeration. Cold insulation protects against surface condensation, ice buildup and most importantly process stability.

Typical materials used for cold insulation are

- Cellular glass
- Poli-Isocyanurate (PIR) foam
- Nano porous insulation

**Figure 3.1: Example of a cold insulation shoe support**

#### 3.3.1.2. *Supporting*

Cold pipes are typically designed with hard scale insulation pads. These insulation pads can be loadbearing. Because of the loadbearing property of cold insulation the supports can be mounted around the insulation rather than directly onto the pipe. This has the advantage that a heat transfer through the steel pipe support is minimized.
If the loads on the support become too high to transfer onto the insulation, then the support shall be mounted directly onto the pipe. This creates a heat flow. The flow will be mitigated by separating the support from the steel structure. Early designs incorporated wooden plates and new systems make use of pressure resistant foams or plastics.

### 3.3.2. Hot systems (ambient up to 500 [ºC])

#### 3.3.2.1. *Insulation*

For above ambient system (and below 500 [ºC]) hot insulation is applied to protect the process conditions and minimize heat loss. Hot insulation maintains desired temperatures for products, to avoid solidification and maintains the right viscosity. Hot insulation may be combined with heat tracing. Heat tracing is the addition of external heat into a system, typical examples are electrical tracing or steam tracing. Typical materials used for hot insulation are

- Mineral wool
- Cellular glass

Above ambient piping systems shall be thermally insulated for process conditions, if economically justified or for safety considerations.

**Figure 3.2: Example of a pipe shoe support**

#### 3.3.2.2. *Supporting*

Pipe systems above ambient temperatures but below 500 [ºC] are typically supported with the support directly mounted to the pipe. This is done because the insulation is typically soft and not loadbearing. This category is most common within petrochemical plants.
This direct mounting system does create a heat leak.

### 3.3.3. Hot systems (500[ºC] and above)

Some systems have process conditions that are more extreme than commonly found on petrochemical refineries. The temperatures can reach far above 500 [ºC] and require special attention. These conditions are rare and require specialized design and engineering. The existence is mentioned for reference purpose only.

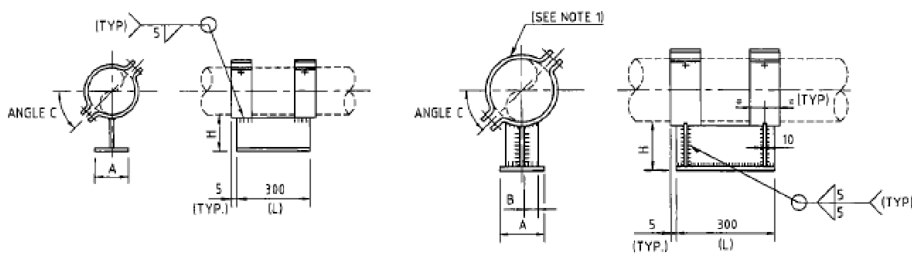
**Figure 3.3: Example of a hot (500+ [ºC]) pipe shoe support with insulation**

## 3.4. Acquisition of information

### 3.4.1. Applicable Jacobs Standards

- Pipe Support methodology book
    - "The objective of this document is to provide the piping designers, standards, guidelines and good supporting practices.

      Supports shall be designed, in accordance with Engineering Standard ES-46001 (standards for pipe support), to carry the loads that exist during the stated design conditions. In additions, supports shall be suitable for carrying the weight of the piping when filled with water during hydrostatic pressure testing, except where alternative testing has been approved." (Jacobs, 2009)
- Standard for Pipe supports
    - Providing details per support type and defined per size of pipe applied on. Details include but are not limited to, dimensions, materials, application and limitations of support types.




FOR LINES 2" (DN50) - 5" (DN125)

FOR LINES 6" (DN150) - 24" (DN600)

| TYPE | NPS | MADE FROM | | A | B | angle | WEIGHT (KG) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | INCH | PROFILE | PLATE | | | C | H=100 | H=150 | H=200 | H=250 | H=300 |
| SC1-2-...-... | 2" | IPE200 | 8mm | 100 | | 45° | 4.7 | 5.6 | | | |
| SC1-2 1/2-...-... | 2 1/2" | | | 100 | | 45° | 4.9 | 5.8 | | | |
| SC1-3-...-... | 3" | | | 100 | | 45° | 5.1 | 6.0 | | | |
| SC1-3 1/2-...-... | 3 1/2" | | | 100 | | 45° | 5.5 | 6.4 | | | |
| SC1-4-...-... | 4" | | | 100 | | 45° | 6.7 | 7.8 | | | |
| SC1-5-...-... | 5" | | | 100 | | 45° | 7.5 | 8.4 | | | |
| SC1-6-...-... | 6" | | 10mm | 150 | 40 | 40° | 11.0 | 12.8 | 14.6 | 16.3 | 18.2 |
| SC1-8-...-... | 8" | | | 150 | 45 | 45° | 12.1 | 14.0 | 15.8 | 17.7 | 19.6 |
| SC1-10-...-... | 10" | | | 150 | 45 | 45° | 14.9 | 16.8 | 18.6 | 20.5 | 22.4 |
| SC1-12-...-... | 12" | | | 200 | 65 | 45° | 17.8 | 20.0 | 22.2 | 24.4 | 26.6 |
| SC1-14-...-... | 14" | | | 200 | 65 | 45° | 18.7 | 20.9 | 23.0 | 25.2 | 27.4 |
| SC1-16-...-... | 16" | | | 250 | 95 | 45° | 27.5 | 30.2 | 32.9 | 35.5 | 38.0 |
| SC1-18-...-... | 18" | | | 250 | 95 | 45° | 29.3 | 32.0 | 34.6 | 37.1 | 39.8 |
| SC1-20-...-... | 20" | | | 300 | 120 | 45° | 33.7 | 36.2 | 39.3 | 42.0 | 45.1 |
| SC1-22-...-... | 22" | | | 300 | 120 | 45° | 57.7 | 60.8 | 63.8 | 66.9 | 69.9 |
| SC1-24-...-... | 24" | | | 300 | 120 | 45° | 59.9 | 62.1 | 65.2 | 68.3 | 71.3 |

| H | INSUL. THICKNESS |
|---|---|
| 100 | 70mm MAX |
| 150 | 120mm MAX |
| 200 | 170mm MAX |
| 250 | 220mm MAX |
| 300 | 270mm MAX |

Figure 3.4: Overview of dimensions and weight for standard pipe shoe supports (Jacobs, 2013)

### 3.4.2. Analysis methods

To analyze the heat flow through pipe supports two different approaches will be used. The first is a one dimensional analytical approach for steady state problems. As done in the theoretical basis. The second is a numerical finite element approach, executed with Femap. Both approaches have their respective advantages and disadvantages.

#### 3.4.2.1. *One dimensional analytical calculations*

The on dimensional calculations will be done in accordance to the theory as stated in “Toegepaste energieleer”. (Taal, 2012)

#### 3.4.2.2. *Numerical with Femap*

Femap is a finite element calculator in a 3d environment. That allows modeling all relevant boundary conditions to generate an accurate calculation. Highly accurate results can be achieved, but a thorough understanding of the program is needed. The calculations are relatively easily adjusted in regards of the boundary conditions. Altering the dimensions however is time consuming.

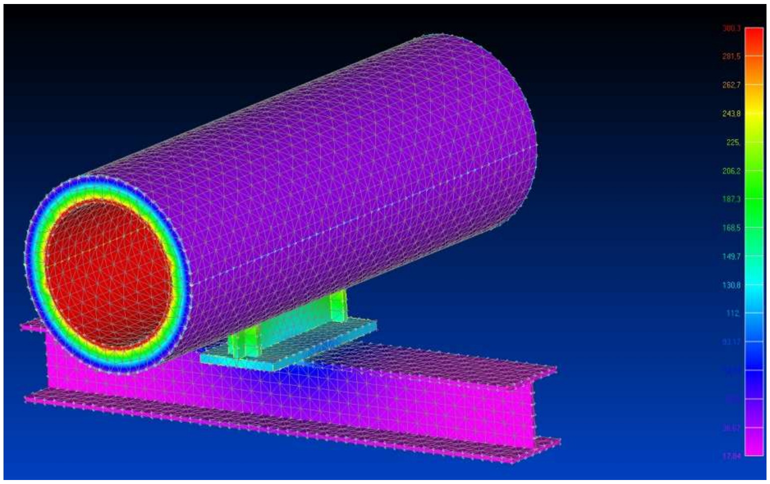


**Figure 3.5: Example of the temperature distribution through an insulated pipe on a HE140A beam**

### 3.4.3. Meteorological data

To determine the variables required for the convective heat transfer the year averages of the location are taken into consideration

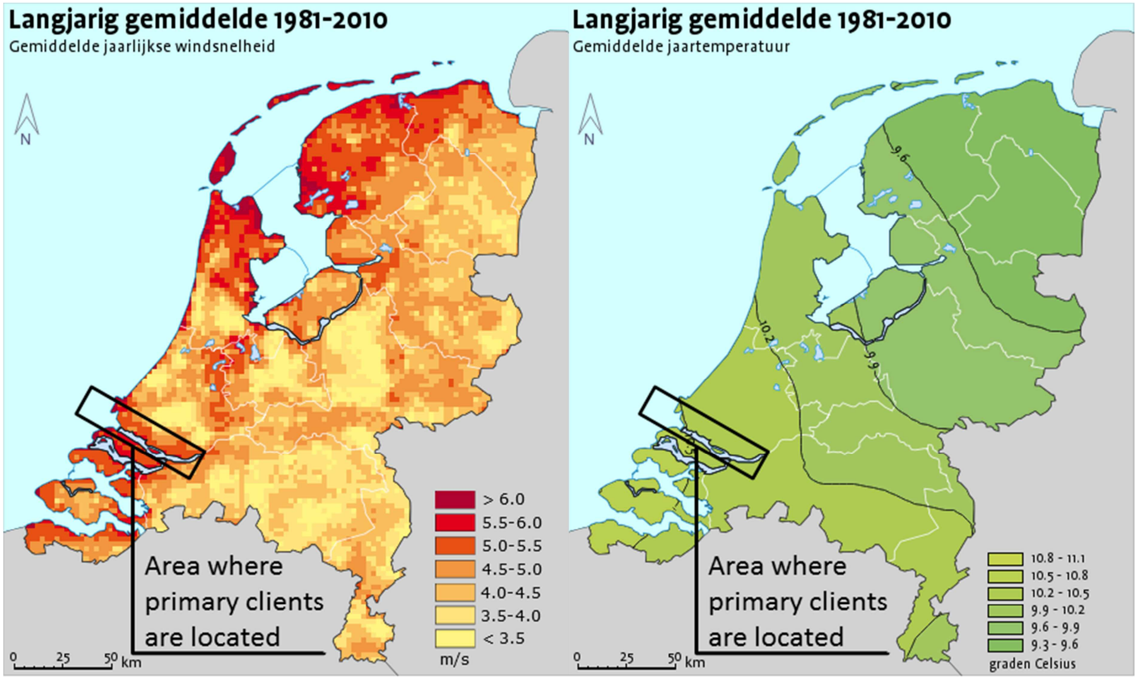



**Figure 3.6: Mean wind speeds and temperatures in the Netherlands from 1981 up to 2010 (Koninklijk Nederlands Meteorologisch Instituut)**

The average temperature per year is within the limits of 9.9[ºC] and 10.2[ºC]. The work value will be 10[ºC].

The value of the forced convection is determined by the wind speed. The average wind speed in the Rotterdam Harbor area ranges between 5[m/s] and 5.5 [m/s]. The work value is set at 5.25[m/s]. The value of the convective heat transfer is described through the following empirical equation, applicable for: 2[m/s] < v < 20[m/s].

$h_c(v) = 10.45 - v + 10\sqrt{v}$ (Engineering Toolbox)

$h_c(5.25) = 28.11 \approx 28$ [W/m$^2$K]

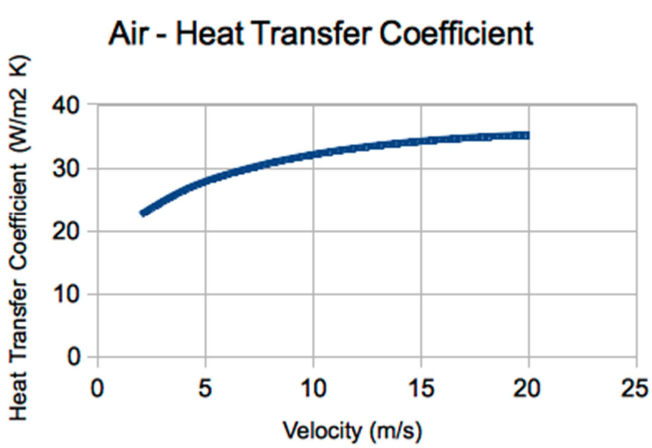



**Figure 3.7: Graph depicting the heat transfer coefficient for air at wind speed (v)** (Engineering Toolbox)

# 4. Method of Approach

The approach is based on a growing understanding of the heat flow through a pipe support. First the literature study is done to form a theoretical basis. After achieving a sound theoretical basis a deeper understanding can be achieved through modeling finite element analysis. To ensure correct results field measurements will be done, against which the analyzed models can be checked. When the results are satisfying a mathematical formulation will be sought.
The following paragraphs will elaborate on all phases as shown in figure3.1.

## 4.1. Workflow

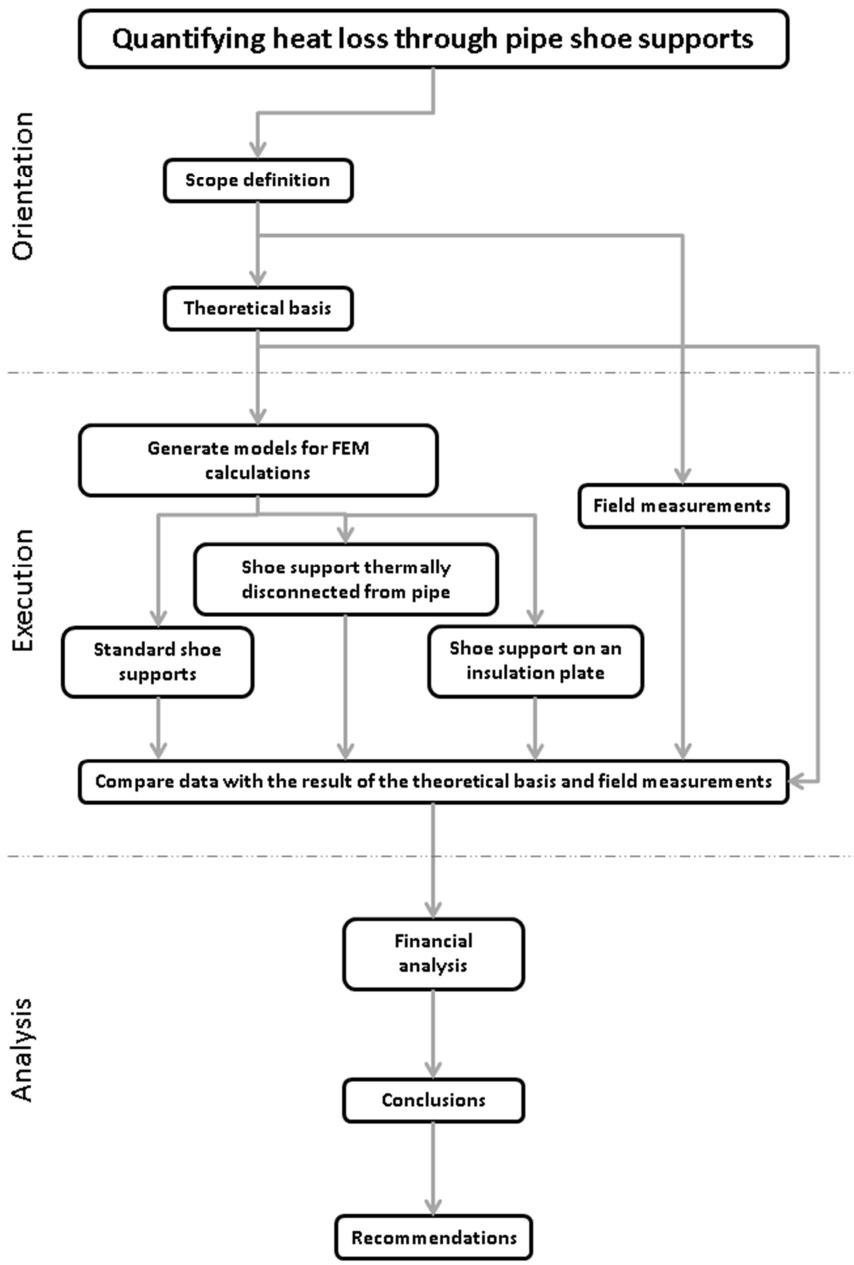



Figure 4.1: Graphical representation of work methodology

## 4.2. Scope definition

The aim of the assignment is to quantify the heat losses for common pipe supporting solutions and provide insight in possible savings. The scope of work is formulated to cover a large range of pipe supporting yet remain manageable within the time limits of a graduation thesis.

### 4.2.1. Support shoe solutions

Three different support shoe solutions will be assessed, the Jacobs standard pipe shoe support (left), a solution that thermally separates the pipe shoe from the pipe (mid) and a solution that separates the pipe shoe from the steel (right).

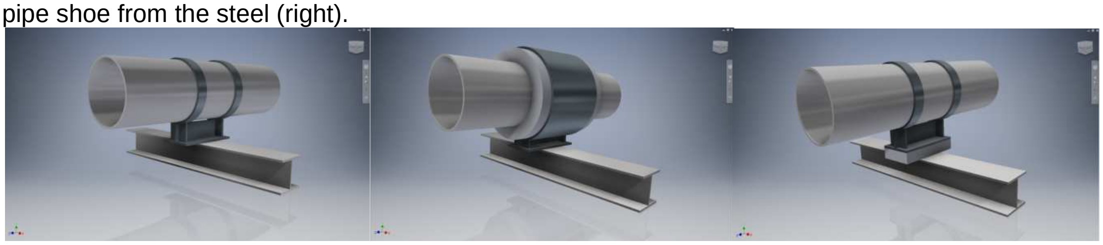


**Figure 4.2: Standard pipe shoe, Pipe shoe on an insulation plate and a pipe shoe with a disconnected**

### 4.2.2. Temperature range

The temperature range is set from 0 to 500[ºC]. Most of the piping systems in refineries fall within this range.

### 4.2.3. Pipe sizes and insulation

The different pipe shoe solutions will be applied on different pipe sizes and insulation thicknesses. The pipe sizes reviewed will be 4" up to and including 20" and the insulation 50[mm], 60[mm] & 70[mm] of Rockwool insulation.

- The pipe material is Carbon steel with $\lambda = 44[W/mK]$ (Taal, 2012)
- The insulation material is Rockwool with $\lambda = 0.04[W/mK]$ (Taal, 2012)
- The shoe insulation material is Monolux-500 with $\lambda = 0.19[W/mK]$ (Promat, 2016)

### 4.2.4. Exclusions

The following topics will not be addressed within the scope of this assignment.

- Heat radiation will not be incorporated. To calculate the effective heat radiation the surrounding environment needs be analyzed, to determine view factors, heat absorption from other heat sources and more (Taal, 2012) .The results generated are to be generic and not location specific.
- The insulation materials are limited to Rockwool and Monolux-500. If more materials would be reviewed the amount of analysis models would become more than can be analyzed in the available time.
- Insulation thicknesses higher than 70[mm] will not be incorporated. The dimensions of the shoes need to be adjusted when this limit is passed. As is determined in the Jacobs standard support book.

### 4.2.5. Summarized

- Shoe support solutions.
    - Jacobs standard pipe shoe supports.
    - Pipe shoe support that are thermally separated from the pipe.
    - Pipe shoe supports on insulation plates, separating the shoe from the steel.
- Temperature range.
    - 0[ºC] to 500[ºC].
- Pipe sizes and Insulation.
    - Pipe sizes from 4" to 20".
    - Insulation thickness 50[mm], 60[mm], 70[mm].

## 4.3. Theoretical basis

To create an understanding of the workings of the steady state thermal situation of a pipe shoe, several comparable situations will be analyzed. The situations applicable are:

- Conduction:
  - o Heat flow through a multi layered pipe.
  - o Heat flow through a pipe shoe support.
- Convection:
  - o Finned cooling.

### 4.3.1. Heat Flow through a multilayered pipe

The heat transfer through an insulated pipe can be calculated as a multilayered pipe. The heat transfer is equal to the temperature difference divided by the total resistance of the assembled layers.
The calculations are based on the theory as presented in "Toegepaste Energieleer" (Taal, 2012).

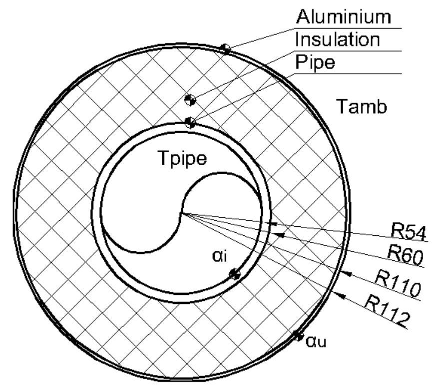



Figure 4.3: Thermal problem, 4[Inch] pipe, 50[mm] insulation and 2[mm] aluminum cladding

The Example calculation in based on:

- Pipe size 4"
- Rockwool insulation 50[mm]
- Aluminum protective sheeting 2[mm]

$$\phi_h = \frac{T_{fluïdum.i} - T_{fluïdum.u}}{R_{tot}}$$

$$R_{tot} = \frac{1}{\alpha_i}\frac{1}{2\pi R_i l} + \sum_{j=1}^{j=n} \frac{1}{2\pi l \lambda} ln \frac{R_{j+1}}{R_j} + \frac{1}{\alpha_u}\frac{1}{2\pi R_{n+1} l}$$

With

$0[C] \leq T_{pipe} \leq 500[C]$
$T_{amb} = 10[C]$
$\lambda_{pipe} = 44[W/mK]$
$\lambda_{insulation} = 0.04[W/mK]$
$\lambda_{alluminium} = 240[W/mK]$
$\alpha_i = 300[W/m^2K]$ *(assumed)*
$\alpha_u = 28[W/m^2K]$

$$R_{tot} = \frac{1}{300}\frac{1}{2\pi 0.054 * 1} + \frac{1}{2\pi 1 * 44}\ln\frac{0.060}{0.054} + \frac{1}{2\pi 1 * 0.04}\ln\frac{0.110}{0.060} + \frac{1}{2\pi 1 * 240}\ln\frac{0.112}{0.110} + \frac{1}{28}\frac{1}{2\pi 0.112 * 1}$$

$$\phi_h = \frac{T_i - 10}{R_{tot}}$$

Table 4.31: Results of calculation

| $T_i$ = | $\Phi_h$=[W] |
|---:|---:|
| 0 [ºC] | -4.04 |
| 100 [ºC] | 36.40 |
| 200 [ºC] | 76.84 |
| 300 [ºC] | 117.28 |
| 400 [ºC] | 157.72 |
| 500 [ºC] | 198.17 |

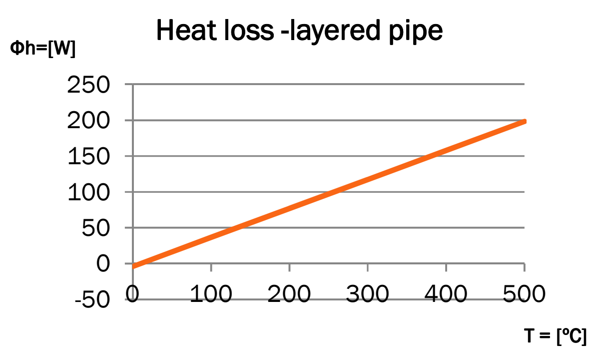



Figure 4.4: Heat transfer through a multi layered pipe

### 4.3.2. Heat flow through conduction to a supporting structure

A standard pipe shoe support creates a link between the hot pipe and cold structural steel. The temperature difference will lead to heat transfer from the pipe to the structural steel. The situation will be analyzed based on a 1 dimensional model. The outcome of this analysis will be indicative and is expected to be below the values return by a finite element calculation. The calculation is based on the theory as presented in “Toegepaste Energieleer” (Taal, 2012).

The Example calculation in based on:

- Pipe shoe support for on a 4” pipe.
- Rockwool insulation 50[mm].
- Aluminum protective sheeting 2[mm].

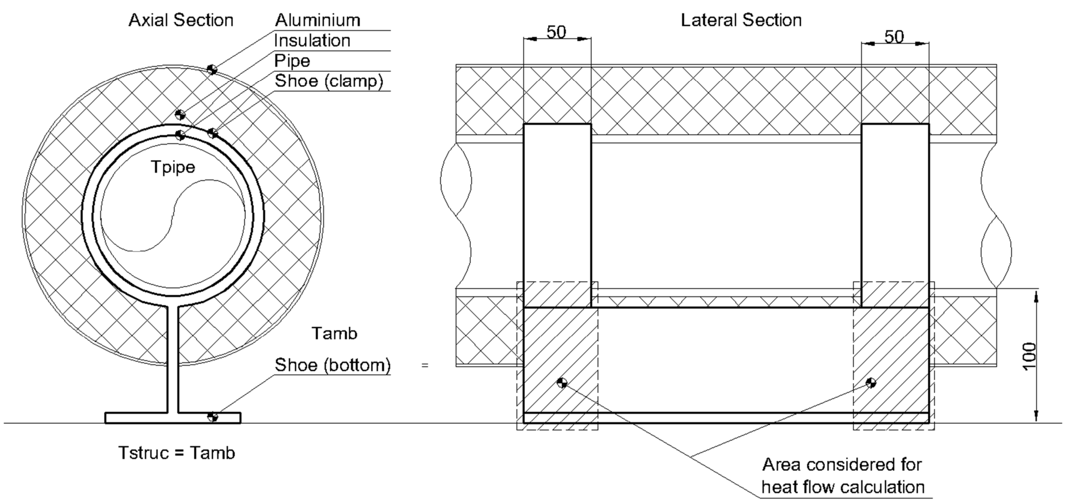



Figure 4.5 Sketch of conductive thermal problem

$$\phi_{h,Conductive} = \frac{T_{fluïdum.i} - T_{fluïdum.u}}{R_{tot}}$$

$$R_{tot} = \frac{1}{\alpha_i} + \frac{d}{\lambda} + \frac{1}{\alpha_u}$$

With

$0[C] \leq T_{pipe} \leq 500[C]$
$T_{amb} = 10[C]$
$\lambda_{pipe} = 44[W/mK]$
$Plate\ thickness = 0.008[m]$
$A = 0.050 * 0.008$
$\alpha_i = 300[W/m^2K]$
$\alpha_u = 999[W/m^2K]$ *(no resistance assumed: steel to steel contact)*

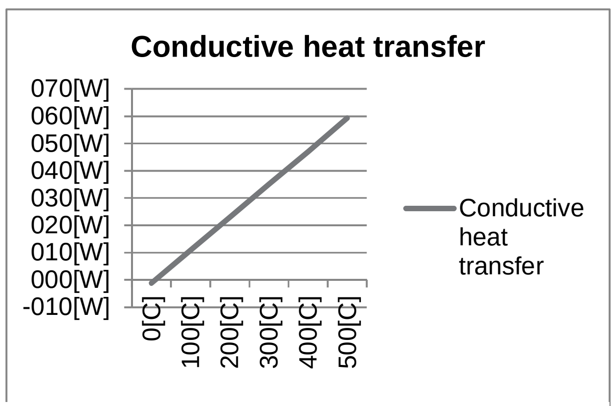



**Figure 4.6: Graph of conductive heat transfer through a pipe shoe**

**Table 4.7: Conductive results**

| Pipe temperature | Results |
|---|---|
| **0[ºC]** | -1.21[W] |
| **100[ºC]** | 10.90[W] |
| **200[ºC]** | 23.00[W] |
| **300[ºC]** | 35.11[W] |
| **400[ºC]** | 47.00[W] |
| **500[ºC]** | 59.33[W] |

### 4.3.3. .Finned cooling

The convective heat transfer through the pipe shoe can be approached as a cool fin. To calculate the convective heat transfer as a through a cool fin some assumption have to be made. The assumptions are about the equivalent length of the pipe shoe compared to a cool fin. Therefore three options are calculated. The calculation is based on the theory as presented in “Toegepaste Energieleer” (Taal, 2012).

The Example calculation in based on:

- Pipe shoe support for on a 4” pipe.
- Rockwool insulation 50[mm].
- Aluminum protective sheeting 2[mm].

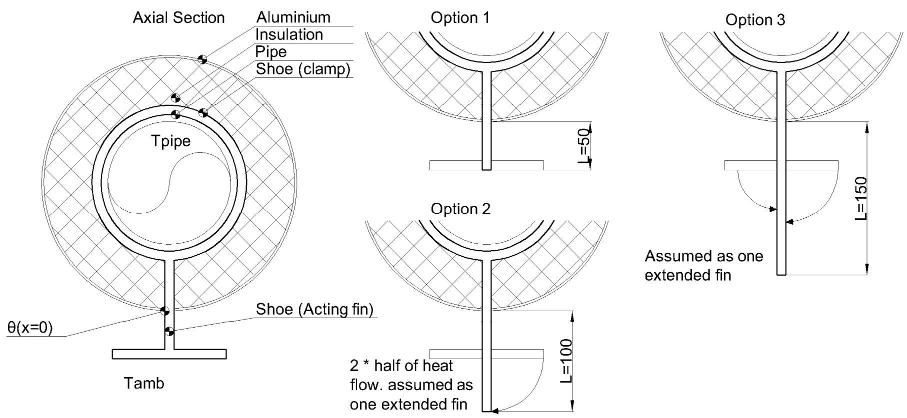



**Figure 4.8 Sketch of convective thermal problem**

$$\phi_h = \frac{\sinh(x) * mL + \frac{\alpha}{m\lambda} * \cosh(x) * mL}{\cosh(x) * mL + \frac{\alpha}{m\lambda} * \sinh(x) * mL} * M$$

With

$0[C] \leq T_{pipe} \leq 500[C]$

$T_{amb} = 10[C]$

$\lambda_{pipe} = 44[W/mK]$

$\alpha = 28[W/m^2K]$

$\theta = T_{pipe} - T_{amb}$

**Table 4.3.1: variables per option**

| Overview of optional variables | Option 1: $x = L = 0.05$ | Option 2: $x = L = 0.10$ | Option 3: $x = L = 0.15$ |
|---|---|---|---|
| $\boldsymbol{sinh = \frac{e^x - e^{-x}}{2}}$ | 0.05 | 0.10 | 0.15 |
| $\boldsymbol{cosh = \frac{e^x + e^{-x}}{2}}$ | 0.100 | 1.01 | 1.01 |
| $\boldsymbol{m = \sqrt{\alpha O / \lambda A}}$ | 12.61 | 12.61 | 12.61 |
| $\boldsymbol{M = \sqrt{\alpha O \lambda A} * \theta_{x=0}}$ | 1.33*$\theta_{x=0}$ | 1.33*$\theta_{x=0}$ | 1.33*$\theta_{x=0}$ |

**Table 4.3.2: Results per option**

| Pipe temperature | Results option 1 | Results option 2 | Results option 3 |
|---|---|---|---|
| **0[ºC]** | -1.33[W] | -1.99[W] | -2.64[W] |
| **100[ºC]** | 12.00[W] | 17.91[W] | 23.72[W] |
| **200[ºC]** | 25.35[W] | 37.80[W] | 50.07[W] |
| **300[ºC]** | 38.68[W] | 57.70[W] | 76.42[W] |
| **400[ºC]** | 52.03[W] | 77.59[W] | 102.78[W] |
| **500[ºC]** | 65.37[W] | 97.48[W] | 129.13[W] |

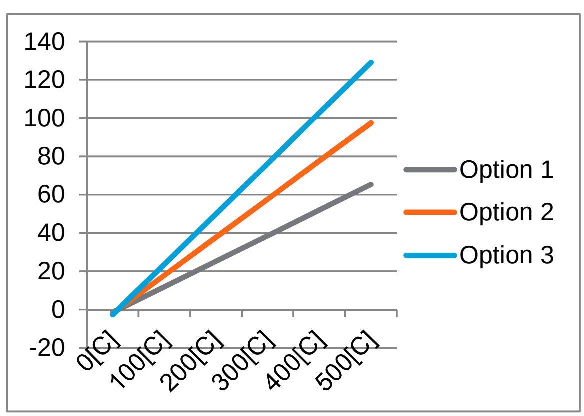



**Figure 4.9: Graph of convective heat transfer**

## 4.4. Finite element modeling

### 4.4.1. Orientation on finite element modeling

In the first stage of the finite element modeling (here after: FEM) analysis the method of modeling finite element calculations will be explored. The focus is to discover the correct way of modeling heat flow through pipe shoes. The main questions that need to be answered are:

- How to model thermal loads?
    - How to model the thermal input?
        - Is it required to model flowing liquid or can a set temperature be used?
    - How to model convection?
- How to model conduction through a material?
- How to model conduction from solid to solid?
- Can the appropriate data be generated
    - Temperature distribution through the different elements
    - Heat flux through the different elements
    - Total heat flux through the pipe show.

When the above mentioned questions have been answered the analysis models can be generated.

### 4.4.2. Desired results

The creation of models will be based on goals to be achieved. The goal is to generate results that can be used to describe the Jacobs standard solution in relation to the pipe temperature and insulation thickness, as well as describing the possible gains by using insulation methods.

- Finding equations that describe the heat loss through pipe shoes, per pipe size and support solution
    - Determine the heat transfer in [W], per pipe size and insulation thickness.
        - For standard pipe shoe support
        - For pipe shoes on an insulation plate
        - For pipe shoes with a thermally disconnected clamp
    - State equations for the insulation solutions reviewed, per pipe size and insulation thickness.
        - Standard pipe shoe support
            - Assumed equation: $\Phi_{h,Standard}(T) = A * T^b + C$
        - Pipe shoe on an insulation plate.
            - Assumed equation: $\Phi_{h,Shoe\_on\_plate}(T) = A * T^b + C$
        - Pipe shoe with a thermally disconnected clamp.
            - Assumed equation: $\Phi_{h,Disconnected\_Clamp}(T) = A * T^b + C$

### 4.4.3. Analysis Models

Test models will be developed to generate insight in the working of heat flux as a function of the pipe temperature and insulation thickness. This requires geometric models which can be generated using 3D CAD solutions. The thermal settings are added in Femap to generate different temperature scenarios, per combination of pipe size and insulation thickness.

#### 4.4.3.1. *Analysis Models: Jacobs standard pipe shoe supports*

To create a base line of models a range of typical situations based on the Jacobs standard pipe shoe supports will be modeled. This ensures useful results as input in the excel file that will later be built. The results will also be used to compare insulation solutions.

| **Jacobs standard pipe shoe supports<br>Pipe sizes 4[Inch] to20 [Inch]** | | | | |
|---|---|---|---|---|
| **Insu. Thck.** | **T0** | **T1** | **T2** | **T3** |
| 50[mm] | 0[ºC] | 100[ºC] | 300[ºC] | 500[ºC] |
| 60[mm] | 0[ºC] | 100[ºC] | 300[ºC] | 500[ºC] |
| 70[mm] | 0[ºC] | 100[ºC] | 300[ºC] | 500[ºC] |

- $\lambda_{steel} = 44[W/mK]$
- $\lambda_{Alu.} = 240[W/mK]$
- $\lambda_{Rockw.} = 0.04[W/mK]$
- $T_{amb.} = 10[C]$
- $\alpha_i = 300[W/m^2K]$
- $\alpha_{Forced.Convection} = 28[W/m^2K]$
- $\alpha_{Natural.Convection} = 4[W/m^2K]$
- $\lambda_{Solid-Solid} = 0[W/m^2K]$

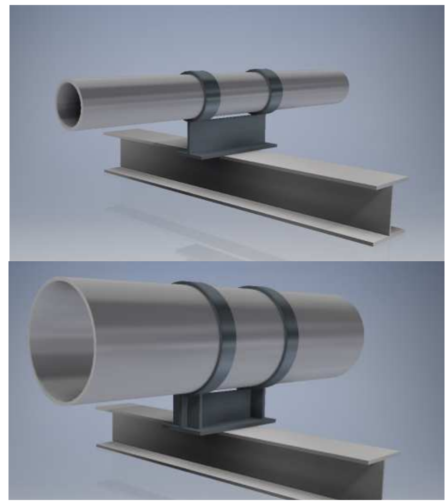


**Figure 4.10: 4 and 10 [Inch] standard pipe shoe support**

#### 4.4.3.2. *Analysis models: Insulation plate applied under Jacobs standard pipe shoe supports*

The first Insulation solution that will be investigated is reducing the conductive heat flow to the supporting structure. The below stated models are based on the Jacobs standard solutions with the addition of an insulator block underneath the pipe shoe. This setup has been chosen to be able to assess the effect of the insulator block without altering other factors of the supporting solution.

| **Pipe shoe supports on insulation plates<br>Pipe sizes 4[Inch] to20 [Inch]** | | | | |
|---|---|---|---|---|
| **Insu. Thck.** | **T0** | **T1** | **T2** | **T3** |
| 50[mm] | 0[ºC] | 100[ºC] | 300[ºC] | 500[ºC] |
| 60[mm] | 0[ºC] | 100[ºC] | 300[ºC] | 500[ºC] |
| 70[mm] | 0[ºC] | 100[ºC] | 300[ºC] | 500[ºC] |

- $\lambda_{steel} = 44[W/mK]$
- $\lambda_{Alu.} = 240[W/mK]$
- $\lambda_{Rockw.} = 0.04[W/mK]$
- $\lambda_{mon.500} = 0.19[W/mK]$
- $T_{amb.} = 10[C]$
- $\alpha_i = 300[W/m^2K]$
- $\alpha_{Forced.Convection} = 28[W/m^2K]$
- $\alpha_{Natural.Convection} = 4[W/m^2K]$
- $\lambda_{Solid-Solid} = 0[W/m^2K]$

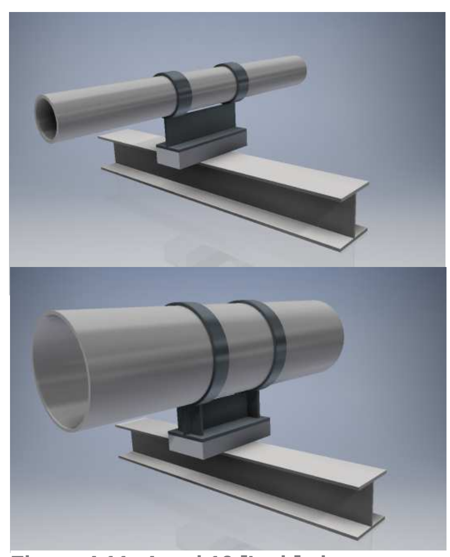


**Figure 4.11: 4 and 10 [Inch] shoe support on an insulation plate**

#### 4.4.3.3. *Analysis models: Separating Jacobs standard pipe shoe from pipe with hard cylindrical Insulation*

Another common insulation solution is the addition of a hard insulator in between the pipe and the clamp of the shoe. Because of the addition of the insulation cylinder the clamp dimension had to be adjusted, also the height of the shoe (bottom half) has been reduced. The shoe length, width and other dimension have been kept the according the Jacobs standards. This has been done to maintain similarity to the original situation whilst keeping a realistic design.

| **Pipe shoe supports with disconnected clamps Pipe sizes 4[Inch] to20 [Inch]** | | | | |
|---|---|---|---|---|
| **Insu. Thck.** | **T0** | **T1** | **T2** | **T3** |
| 50[mm] | 0[ºC] | 100[ºC] | 300[ºC] | 500[ºC] |
| 60[mm] | 0[ºC] | 100[ºC] | 300[ºC] | 500[ºC] |
| 70[mm] | 0[ºC] | 100[ºC] | 300[ºC] | 500[ºC] |

- $\lambda_{steel} = 44[W/mK]$
- $\lambda_{Alu.} = 240[W/mK]$
- $\lambda_{Rockw.} = 0.04[W/mK]$
- $\lambda_{mon.500} = 0.19\left[\frac{W}{mK}\right]$
- $T_{amb.} = 10[C]$
- $\alpha_i = 300[W/m^2K]$
- $\alpha_{Forced.Convection} = 28[W/m^2K]$
- $\alpha_{Natural.Convection} = 4\left[\frac{W}{m^2K}\right]$
- $\lambda_{Solid-Solid} = 0[W/m^2K]$

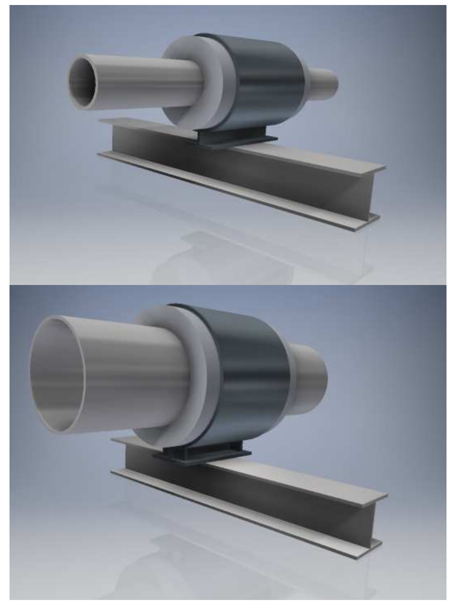


Figure 4.12: 4 and 10 [Inch] pipe shoe with a disconnected clamp

#### 4.4.4. Testing

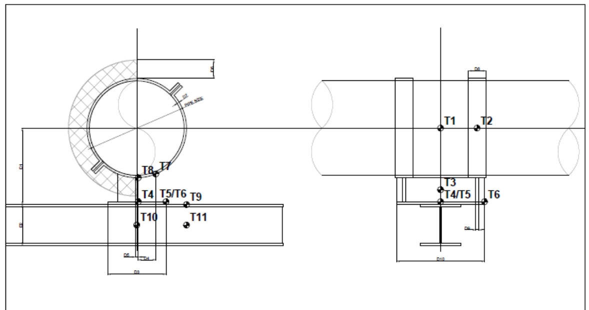
The validity of the models will be tested by performing field measurements and comparing the temperature distribution with that of the developed models. If the supporting situations in the plants are not comparable to the prepared FEM models, then new models will be made to match the supporting situations found in the plant. Collecting the data will be done through the usage of a measurement template. The template has been designed to generate an understanding of the heat flow.

**T1**: temperature outside of pipe. This location is to determine the pipe temperature and to refer to corresponding boundary condition in the analysis models.

**T2**: Temperature on the clamp connecting the pipe shoe to the pipe.

**T3, T4, T5, T6, T7, and T8**: all temperature measurements on the shoe are done to find the temperature distribution of the pipe shoe. The aim is to validate the convective boundary conditions.

**T9, T10 and T11**: all temperature measurements on the beam or other supporting structure are done to find the temperature distribution of the supporting structure. The aim is to validate the convective boundary conditions.




| | | | | | |
|---|---|---|---|---|---|
| PIPE SIZE | | T1 | | D1 | |
| INSU. THICK. | | T2 | | D2 | |
| OPP. TEMP | | T3 | | D3 | |
| Tamb | | T4 | | D4 | |
| Vwind | | T5 | | D5 | |
| ADDITIONAL NOTES/REMARKS /CONDITIONS | | T6 | | D6 | |
| | | T7 | | D7 | |
| | | T8 | | D8 | |
| | | T9 | | D9 | |
| | | T10 | | D10 | |

**Figure 4.13 The measurement template used. See Appendix I**

#### 4.4.5. Determining equations

The generated data will be collected and analyzed using “Matlab”. The choice for “Matlab” was made based on the data handling tools available and previous experience with the program. In particular the “curve fitting application” is a convenient feature of the software package. After collecting the data “Matlab” can generate several different plots but most importantly it can generate the corresponding equation. This greatly reduces the time required to generate the equations that will later be used to drive the excel sheets.

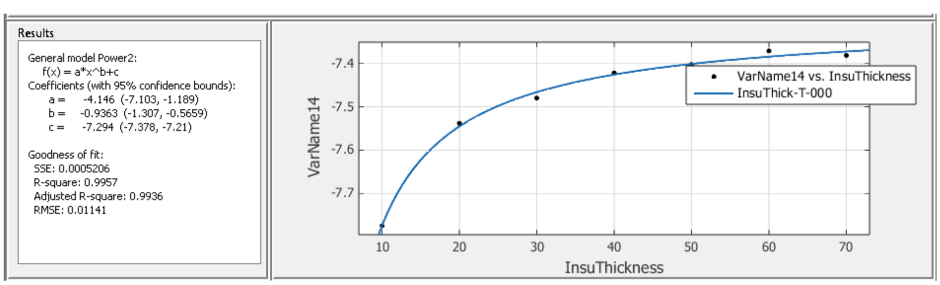



**Figure 4.14 Result of the Matlab curve fitting tool**

### 4.4.6. Excel

The generated equations will be combined with the equation to calculate heat flow through a cylinder of multiple layers. This combination describes the actual mode of heat transfer. The pipe will have a base heat transfer through the insulation. The resulting temperature drop over the length of the pipe will be included in the calculation. The equation will be linear for a steady state system. If the heat transfer per length is known the corresponding pipe temperature can be calculated. The calculated pipe temperature is inserted to calculate the heat transfer per shoe. As the temperature declines through the length of the pipe the heat transfer through the pipe shoes will also decline

## 4.5. Development methods

### 4.5.1. Developing geometrical input

The finite element models will be developed through a parametrical Inventor model. The Inventor model is created to generate geometrical models based on the dimensions stated in the Jacobs pipe support standard book. This eliminates the need to model every geometric change in the different models. Through linking the parameters and adjusting the dimension, a range of geometric changes can be made. The dimensions that can be changed through the parametric input are:

- Pipe outer diameter
- Pipe schedule
- Insulation thickness
- Shoe length
- Shoe width
- Shoe thickness
- Shoe reinforcement plates
- Clamp width

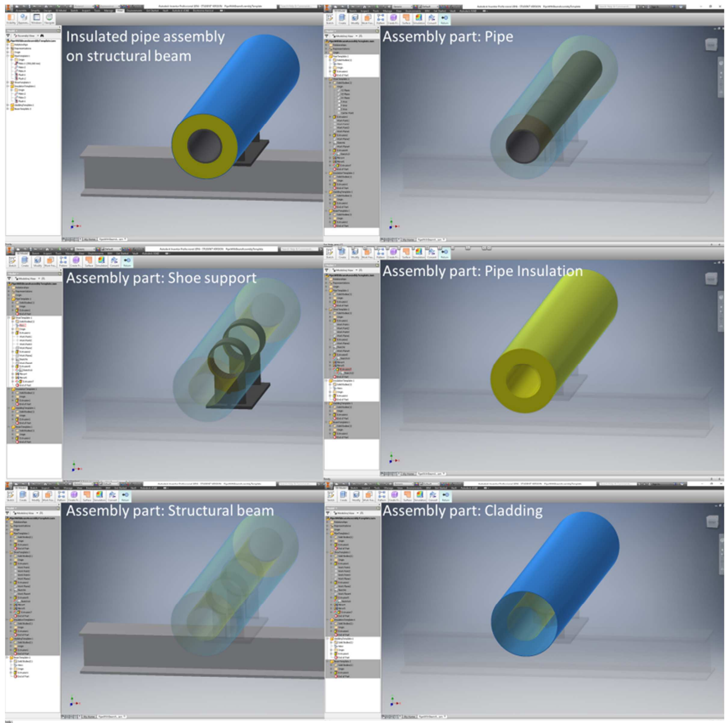



Figure 4.15 Overview of components modeled with Inventor

| Parameter Name | Unit/Type | Equation | Nominal Value | Tol. | Model Value | Key | Exp | Comment |
|---|---|---|---|---|---|---|---|---|
| Model Parameters | | | | | | | | |
| ShoePLateWidth | mm | 100 mm | 100,000000 | | 100,000000 | ☐ | ☑ | |
| SHoePlateTickness | mm | 8 mm | 8,000000 | | 8,000000 | ☐ | ☐ | |
| ShoeBackThickness | mm | 8 mm | 8,000000 | | 8,000000 | ☐ | ☐ | |
| d7 | mm | ShoeBackThickness / 2 ul | 4,000000 | | 4,000000 | ☐ | ☐ | |
| InnDiaClamp | mm | PipeOuterDia | 114,300000 | | 114,300000 | ☐ | ☐ | |
| ClampThickness | mm | 8 mm | 8,000000 | | 8,000000 | ☐ | ☐ | |
| ShoeLenght | mm | 300 mm | 300,000000 | | 300,000000 | ☐ | ☑ | |
| d11 | deg | 0,0 deg | 0,000000 | | 0,000000 | ☐ | ☐ | |
| ClampWidth | mm | 50 mm | 50,000000 | | 50,000000 | ☐ | ☐ | |
| ReinforcementPl... | mm | ClampWidth | 50,000000 | | 50,000000 | ☐ | ☐ | |
| d14 | mm | InnDiaClamp + ClampWidth | 164,300000 | | 164,300000 | ☐ | ☐ | |
| d15 | deg | 0,0 deg | 0,000000 | | 0,000000 | ☐ | ☐ | |
| BOStoCOP | mm | ( InnDiaClamp / 2 ul ) + 100 mm | 157,150000 | | 157,150000 | ☐ | ☐ | |
| ReinformenctSize | mm | 0 mm + ( ShoeBackThickness / 2 ul ) | 4,000000 | | 4,000000 | ☐ | ☐ | |
| d26 | mm | ShoeBackThickness | 8,000000 | | 8,000000 | ☐ | ☐ | |
| d27 | deg | 0,0 deg | 0,000000 | | 0,000000 | ☐ | ☐ | |
| d30 | mm | ShoeLenght | 300,000000 | | 300,000000 | ☐ | ☐ | |
| d31 | deg | 0,0 deg | 0,000000 | | 0,000000 | ☐ | ☐ | |
| d33 | mm | InnDiaClamp | 114,300000 | | 114,300000 | ☐ | ☐ | |

Figure 4.16: Parametric input sheet for pipe shoe supports

### 4.5.2. Developing finite element calculations

Developing the model to calculate using the finite element method is done in multiple steps.

1. The geometry is imported and processed so the boundary condition can later be applied on the correct locations
2. The materials used in the model are loaded or if not available the material properties are entered.
3. Properties are specified. The properties determine how a selected material is used. All properties will be defined as solid. Because the geometry is predefined by the inventor model.
4. The geometry is to be divided into elements. More elements give a more detailed representation. This does make the calculation more complex and will increase the calculation time. Thus the element size is chosen to optimize the calculation time and detail level of the results.
5. The different materials need to be connected to create a path through which the heat can flow. The path is determined from the inside out. Example: the Pipe is connected to the insulation and the insulation to the protective cladding.
6. The mode of heat input and output need to be determined and through which geometry it enters or leaves.
7. The calculation limitations need to be adjusted. Due to the large amount of elements the maximum iterations of the calculations need to be increased. (If this is not done about half the models cannot be calculated.)
8. A selection of results must be selected. Total conductive heat flow, heat distribution etc.
9. The generated results need to be collected and renamed to be able to quickly select the correct results.
10. When all the scenarios are calculated for the given geometry the data can be extracted in one or multiple list files.

# 5. Finite element calculations

To ensure consistent and useful results the calculation models must be built consistently. To ensure this a work method must be established. The input and output must be consistent in all analysis models. The assumed direction of the primary heat flow must be the same in all models. Depending on the desired result from an analysis model one or more variables may be changed. The preference is to change one variable per scenario, however due to the large number of variables this is not possible for all analysis models and scenario's as it would take more time than is available. The following chapters will elaborate on the decisions made.

## 5.1. Determining the variables and constants required

The main variables will be addressed and decisions to include or exclude certain variables will be explained.

### 5.1.1. Heat load variables

The governing variable for the heat transfer in reality is the temperature off the medium combined with the conductivity between the medium and the pipe wall. We are not (yet) interested in the medium conditions. The governing condition in the model will be the temperature of the pipe wall. Simplifying the calculations and the computing time required.
This allows the heat load input to be defined as a temperature, T = [ºC]

### 5.1.2. Boundary conditions

The boundary conditions are chosen to generate accurate results whilst minimizing the complexity and computing time.

#### 5.1.2.1. *Conductive heat flow*

Conductive heat flow is required to transfer the energy through the pipe to the atmosphere where it can be transferred through convection and radiation. For all materials the conductivity needs be known and locked. As the FEM models are setup in [mm] the convective variables need to be converted from [W/mK] to [W/mmK].

#### 5.1.2.2. *Convective Heat transfer*

Convective heat flow is a two part system there is forced convection driven by winds and natural convection which is driven by the heating of the air near the surface and the resulting air flow. The models will be setup to accommodate both modes of heat transfer. Again the Units need to be converted from [W/m$^2$K] to [W/mm$^2$K].

## 5.2. Output variables

The main goal is to quantify the energy lost through pipe shoes for any given time. The analysis model provides two types of output.

- Temperature [ºC].
- Heat transfer [W].

### 5.2.1. Temperature distribution

We are primarily interested in energy flow. Assessing the validity of the models would be difficult without insight into the temperature distribution. The temperature output is given as an absolute value. This temperature will be measured in a plant to test the validity of the analysis models.

### 5.2.2. Heat flow

The heat flow is required to determine the heat output of the shoe. The output can be generated for the complete shoe but also for selected parts and areas. This will provide additional insight into the heat transfer.

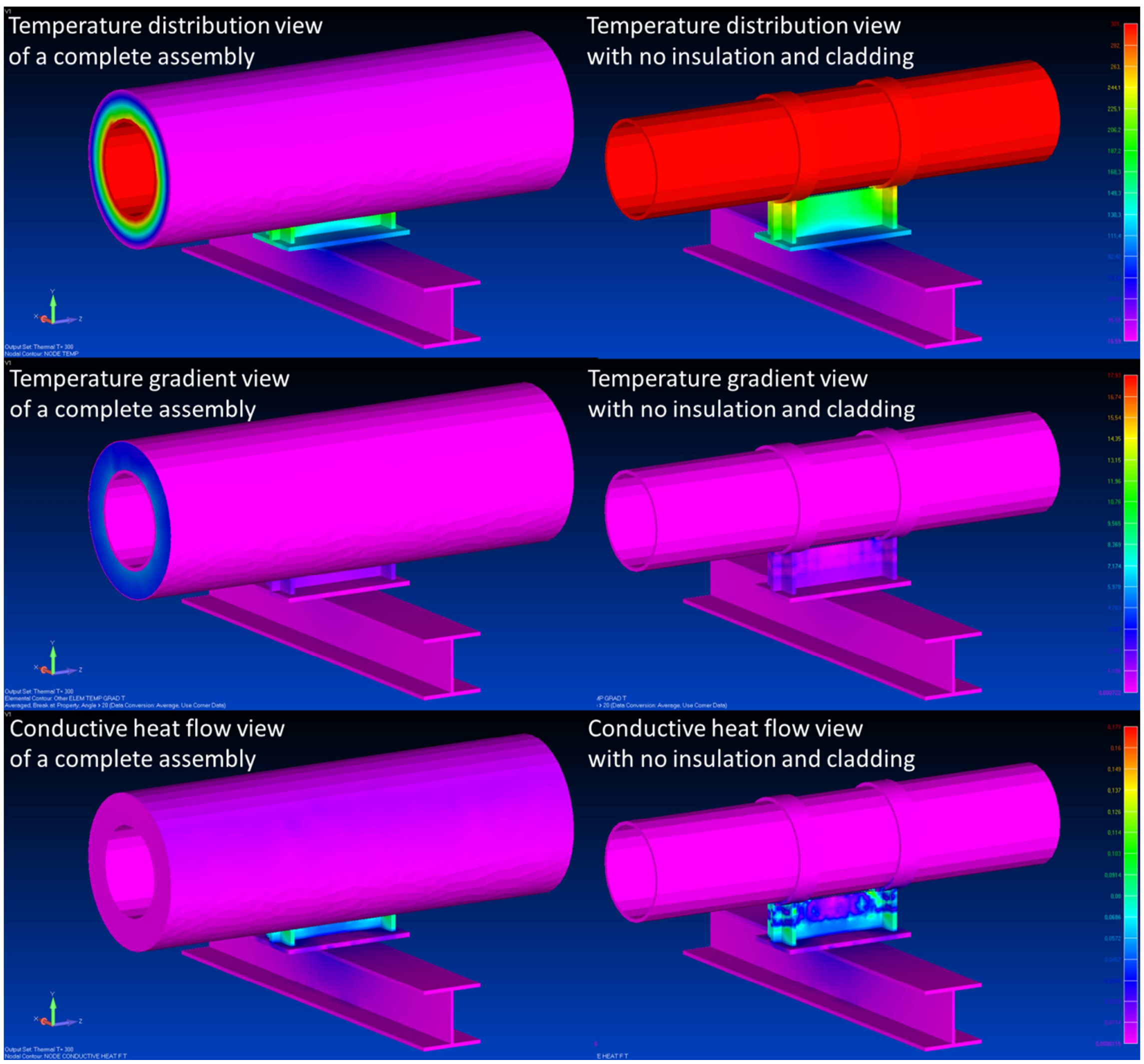



Figure 5.1: Temperature distribution, gradient and conductive heat flow through a hot pipe

### 5.3. Direction of heat transfer

The primary direction of the heat flow will be dictated from the pipe outward. This ensures the correct sequence is used and the model will be analyzed correctly. Slight variations exist between the models describing normal practice and the two insulation solutions reviewed. However the primary direction is the same in all models.

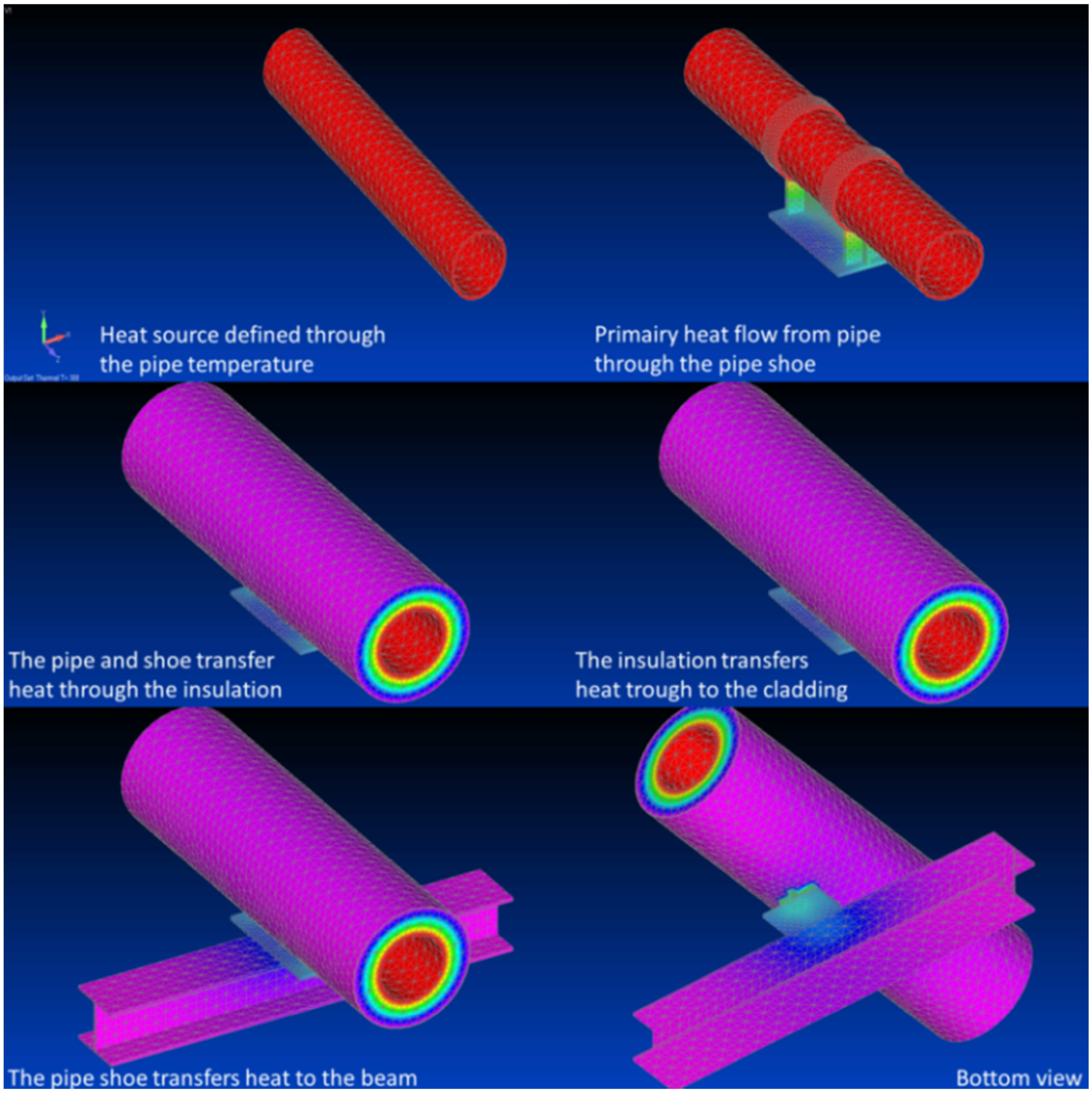



Figure 5.2: Direction of heat transfer

The heat flow is directed by defining the contact surfaces. The geometry has been divided as such that the contact surfaces can be modeled properly. If two contact surface are not properly aligned the chance exists that the calculation will fail or give incorrect results. The flowing picture shows the contact surface between the different parts of the assembly.

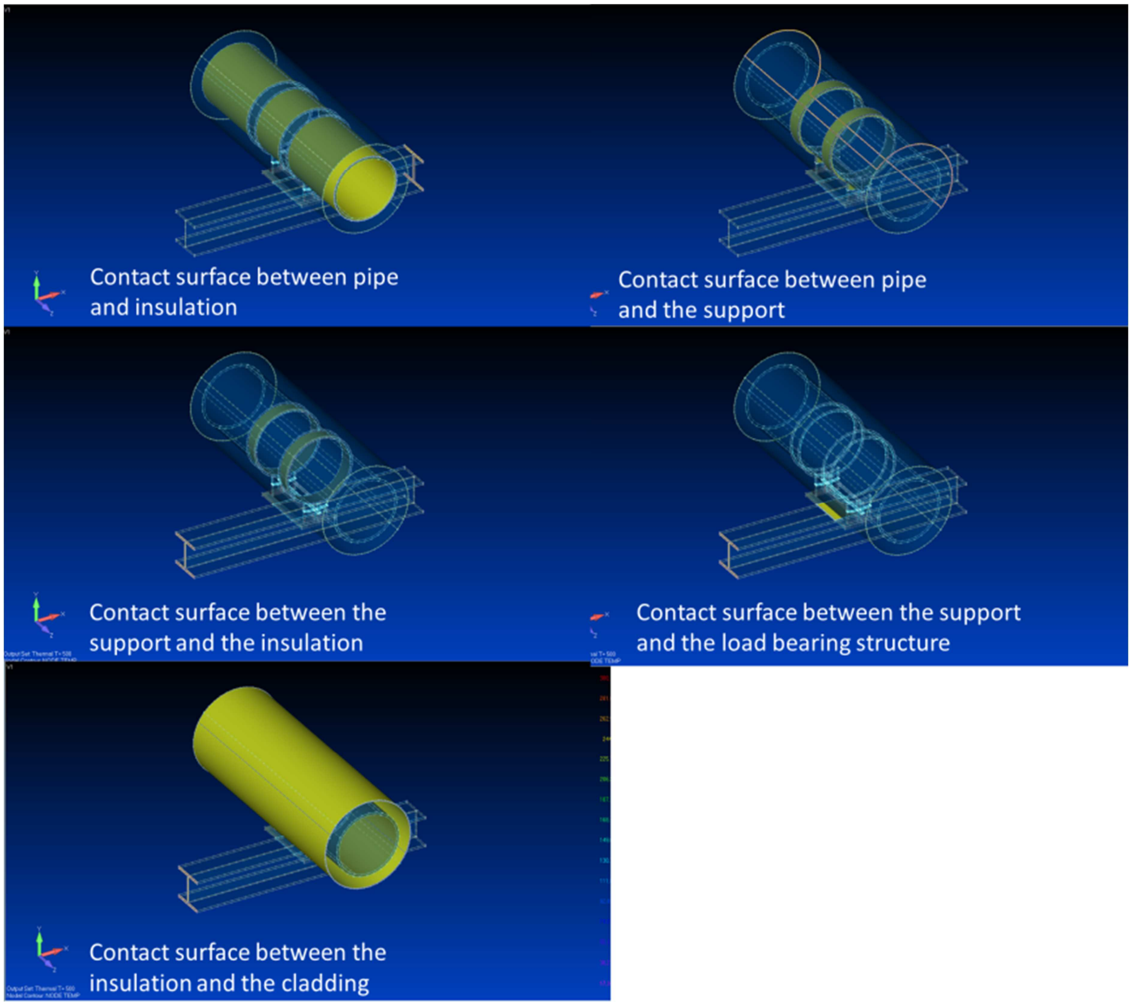



**Figure 5.3: Contact surface for conductive heat transfer between the components that make up the pipe assembly.**

## 5.4. Analysis of standard practice situations

To best approach the actual heat transfer, models are made according to the Jacobs pipe support standard. These models give high quality output for supporting solutions. However their applicability is limited and cannot easily be extrapolated because multiple dimensional variables change simultaneously.

Below are some examples of dimensions that differ between supports on a 4”and 10” pipe.

| Variable | 4” Pipe | 10” Pipe |
|---|---|---|
| Pipe Outer Diameter | 114.3[mm] | 273.1[mm] |
| Pipe Wall Thickness | 6.02[mm] | 9.27[mm] |
| Shoe Width | 100[mm] | 150[mm] |
| Clamp width | 50[mm] | 60[mm] |
| Enforcement bars | N/A | 45[mm] |

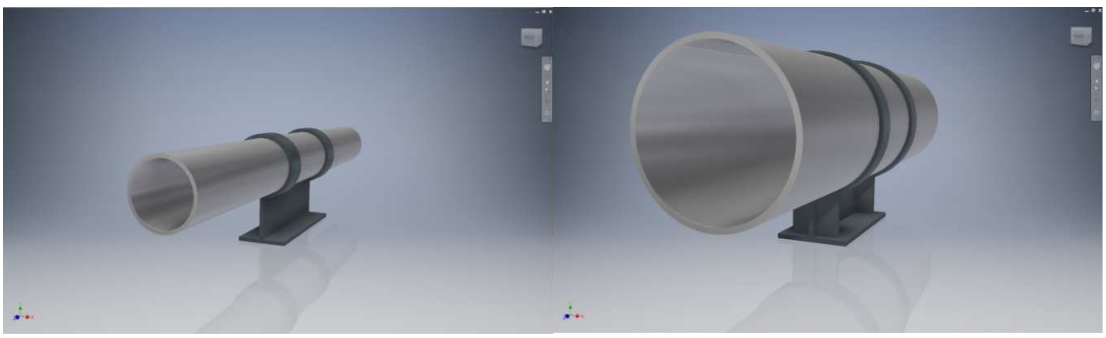


Figure 5.4: Graphical representation of the differences between 4[Inch] and 10[Inch] pipe shoes

# 6. Results

### 6.1.1. Results according to Theoretical 1 dimensional calculations

The calculations as done in the theoretical basis have been duplicated in excel to calculate the heat transfer per pipe size and temperature. The sum of heat transfer through convection and conduction are calculated based on the geometry of pipe shoe per size. The excel file allows to change material properties and dimension. Because of this heat transfer through the pipe on an insulation plate can also be calculated with this form.

**Conductive heat transfer**

$$\phi_{h,Conductive} = \frac{T_{fluïdum.i} - T_{fluïdum.u}}{R_{tot}}$$

$$R_{tot} = \frac{1}{\alpha_i}\frac{1}{2\pi R_i l} + \sum_{j=1}^{j=n}\frac{1}{2\pi l\lambda} ln\frac{R_{j+1}}{R_j} + \frac{1}{\alpha_u}\frac{1}{2\pi R_{n+1} l}$$

**Convective heat transfer**

$$\phi_{h,Convective(fin)} = \frac{\sinh(x) * mL + \frac{\alpha}{m\lambda} * \cosh(x) * mL}{\cosh(x) * mL + \frac{\alpha}{m\lambda} * \sinh(x) * mL} * M$$

With

$$m = \sqrt{\alpha O/_{\lambda A}}$$

$$M = \sqrt{\alpha O\lambda A} * \theta_{x=0}$$

$$\theta = T_{pipe} - T_{amb}$$

**Total heat transfer**

$$\phi_h = a * \phi_{h,Forced\_convection} + (1 - a) * \phi_{h,Natural\_convection} + \phi_{h,Conductive}$$

**1D theoretical heat transfer calculation**

| General Input variables | | | |
|---|---|---|---|
| Tpipe | 500[ºC] | insu thick | 0,07[m] |
| Tamb | 10[ºC] | Shoe Height | 0,1[m] |

*green fields are adjustable variables

| a = Weight in conv. Total 0,6 | 4Inch] | 6Inch] | 8Inch] | 10Inch] | 12Inch] | 14Inch] | 16Inch] | 20Inch] |
|---|---|---|---|---|---|---|---|---|
| **Tw** | 465 | 465 | 465 | 465 | 465 | 465 | 465 | 465 |
| **T0** | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| **Omtrek** | 0,6 | 0,92 | 0,96 | 0,96 | 1,12 | 1,12 | 1,36 | 1,56 |
| **Opperv** | 0,0024 | 0,0046 | 0,0048 | 0,0048 | 0,0056 | 0,0056 | 0,0068 | 0,0078 |
| **L** | 0,13 | 0,18 | 0,18 | 0,18 | 0,23 | 0,23 | 0,28 | 0,33 |
| **α** | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 |
| **λ** | 44 | 44 | 44 | 44 | 44 | 44 | 44 | 44 |
| **θ** | 455,00 | 455,00 | 455,00 | 455,00 | 455,00 | 455,00 | 455,00 | 455,00 |
| **M** | 6,06E+02 | 1,04E+03 | 1,08E+03 | 1,08E+03 | 1,26E+03 | 1,26E+03 | 1,54E+03 | 1,76E+03 |
| **Sinh** | 0,13 | 0,18 | 0,18 | 0,18 | 0,23 | 0,23 | 0,28 | 0,34 |
| **Cosh** | 1,01 | 1,02 | 1,02 | 1,02 | 1,03 | 1,03 | 1,04 | 1,05 |
| **m** | 12,61 | 11,28 | 11,28 | 11,28 | 11,28 | 11,28 | 11,28 | 11,28 |
| **result Forced convection * 1** | **108[W]** | **241[W]** | **251[W]** | **251[W]** | **352[W]** | **352[W]** | **498[W]** | **648[W]** |

| Natural Convection | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Weight in conv. Total 0,4 | 4Inch] | 6Inch] | 8Inch] | 10Inch] | 12Inch] | 14Inch] | 16Inch] | 20Inch] |
| Tw | 465 | 465 | 465 | 465 | 465 | 465 | 465 | 465 |
| T0 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| Omtrek | 0,6 | 0,92 | 0,96 | 0,96 | 1,12 | 1,12 | 1,36 | 1,56 |
| Opperv | 0,0024 | 0,0046 | 0,0048 | 0,0048 | 0,0056 | 0,0056 | 0,0068 | 0,0078 |
| L | 0,13 | 0,18 | 0,18 | 0,18 | 0,23 | 0,23 | 0,28 | 0,33 |
| α | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| λ | 44 | 44 | 44 | 44 | 44 | 44 | 44 | 44 |
| θ | 455,00 | 455,00 | 455,00 | 455,00 | 455,00 | 455,00 | 455,00 | 455,00 |
| M | 2,56E+02 | 4,39E+02 | 4,58E+02 | 4,58E+02 | 5,34E+02 | 5,34E+02 | 6,49E+02 | 7,44E+02 |
| Sinh | 0,13 | 0,18 | 0,18 | 0,18 | 0,23 | 0,23 | 0,28 | 0,34 |
| Cosh | 1,01 | 1,02 | 1,02 | 1,02 | 1,03 | 1,03 | 1,04 | 1,05 |
| m | 5,33 | 4,77 | 4,77 | 4,77 | 4,77 | 4,77 | 4,77 | 4,77 |
| **result Natural convection * 1** | **38[W]** | **88[W]** | **92[W]** | **92[W]** | **132[W]** | **132[W]** | **191[W]** | **252[W]** |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Conv. Total** | **80[W]** | **180[W]** | **187[W]** | **187[W]** | **264[W]** | **264[W]** | **375[W]** | **490[W]** |

| Conductive heat transfer | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 4Inch] | 6Inch] | 8Inch] | 10Inch] | 12Inch] | 14Inch] | 16Inch] | 20Inch] |
| Tpipe | 465 | 465 | 465 | 465 | 465 | 465 | 465 | 465 |
| T2 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 |
| Opperv | 2,40E-03 | 4,60E-03 | 4,80E-03 | 4,80E-03 | 5,60E-03 | 5,60E-03 | 6,80E-03 | 7,80E-03 |
| Alfa1 | 300,00 | 300,00 | 300,00 | 300,00 | 300,00 | 300,00 | 300,00 | 300,00 |
| **Alfa2** (steel to steel contact) | 9999,00 | 9999,00 | 9999,00 | 9999,00 | 9999,00 | 9999,00 | 9999,00 | 9999,00 |
| L1 | 0,1 | 0,1 | 0,1 | 0,1 | 0,1 | 0,1 | 0,1 | 0,1 |
| λ1 | 44 | 44,00 | 44,00 | 44,00 | 44,00 | 44,00 | 44,00 | 44,00 |
| L2 | 0 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |
| λ2 | 9999 | 9999,00 | 9999,00 | 9999,00 | 9999,00 | 9999,00 | 9999,00 | 9999,00 |
| U | 178,35 | 178,35 | 178,35 | 178,35 | 178,35 | 178,35 | 178,35 | 178,35 |
| **Results** | **113[W]** | **217[W]** | **226[W]** | **226[W]** | **264[W]** | **264[W]** | **321[W]** | **368[W]** |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Total** | **193[W]** | **397[W]** | **414[W]** | **414[W]** | **529[W]** | **529[W]** | **696[W]** | **859[W]** |

### 6.1.2. Collected 1D-calculation results

The calculation has been repeated for the applicable scope. The tables summarize the results.

| Results calculated through the sum of 1 dimensional Convective and conductive calculation | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Pipe | Standard shoe support 50[mm] | | | | | | | |
| Temp. | 4Inch] | 6Inch] | 8Inch] | 10Inch] | 12Inch] | 14Inch] | 16Inch] | 20Inch] |
| 0[ºC] | -6[W] | -12[W] | -13[W] | -13[W] | -16[W] | -16[W] | -21[W] | -25[W] |
| 100[ºC] | 37[W] | 75[W] | 78[W] | 78[W] | 100[W] | 100[W] | 131[W] | 161[W] |
| 300[ºC] | 123[W] | 250[W] | 261[W] | 261[W] | 332[W] | 332[W] | 435[W] | 535[W] |
| 500[ºC] | 209[W] | 425[W] | 443[W] | 443[W] | 564[W] | 564[W] | 739[W] | 908[W] |

| Results calculated through the sum of 1 dimensional Convective and conductive calculation | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Pipe | Standard shoe support 60[mm] | | | | | | | |
| Temp. | 4Inch] | 6Inch] | 8Inch] | 10Inch] | 12Inch] | 14Inch] | 16Inch] | 20Inch] |
| 0[ºC] | -6[W] | -12[W] | -13[W] | -13[W] | -16[W] | -16[W] | -21[W] | -25[W] |
| 100[ºC] | 35[W] | 72[W] | 76[W] | 76[W] | 96[W] | 96[W] | 127[W] | 157[W] |
| 300[ºC] | 118[W] | 242[W] | 252[W] | 252[W] | 321[W] | 321[W] | 422[W] | 520[W] |
| 500[ºC] | 201[W] | 411[W] | 429[W] | 429[W] | 546[W] | 546[W] | 718[W] | 883[W] |

| Results calculated through the sum of 1 dimensional Convective and conductive calculation | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Pipe | Standard shoe support 70[mm] | | | | | | | |
| Temp. | 4Inch] | 6Inch] | 8Inch] | 10Inch] | 12Inch] | 14Inch] | 16Inch] | 20Inch] |
| 0[ºC] | -6[W] | -12[W] | -13[W] | -13[W] | -16[W] | -16[W] | -20[W] | -25[W] |
| 100[ºC] | 34[W] | 70[W] | 73[W] | 73[W] | 93[W] | 93[W] | 123[W] | 152[W] |
| 300[ºC] | 114[W] | 234[W] | 244[W] | 244[W] | 311[W] | 311[W] | 410[W] | 506[W] |
| 500[ºC] | 194[W] | 397[W] | 415[W] | 415[W] | 529[W] | 529[W] | 697[W] | 859[W] |

### 6.1.3. Finite Element Models

The geometric shapes created with Inventor have been analyzed using Femap. The table below will clarify the different models that have been analyzed and will state the number of analysis models.

A total of 252 thermal scenarios have been evaluated using FEM.

| Aim of models | Thermal scenario's<br>Geom.* scen.= X | description |
|---|---|---|
| Quantifying the heat loss through standard supporting solutions | 21*4 = 84 | Range: 4" to 20" pipe with insulation thickness 50,60 and 70[mm] |
| Quantifying the heat loss through shoes on a insulation plate | 21*4 = 84 | Range: 4" to 20" pipe with insulation thickness 50,60 and 70[mm] |
| Quantifying the heat loss through separateed pipe shoe clamps | 21*4 = 84 | Range: 4" to 20" pipe with insulation thickness 50,60 and 70[mm] |

### 6.1.4. Collected Results

#### 6.1.4.1. *Overview of results per output area on a pipe shoe*

The output is linked to mean temperatures on key locations of the pipe shoe.

T1A ➔ T1B Pipe clamp to bottom of shoe
T2A ➔ T2B Top of shoe to bottom of shoe
T3A ➔ T3B Pipe Clamp to bottom of reinforcement plate (Not applicable for 4" pipe shoe support)
T4A ➔ T4B Bottom of shoe (Center) to bottom of shoe (Sides)

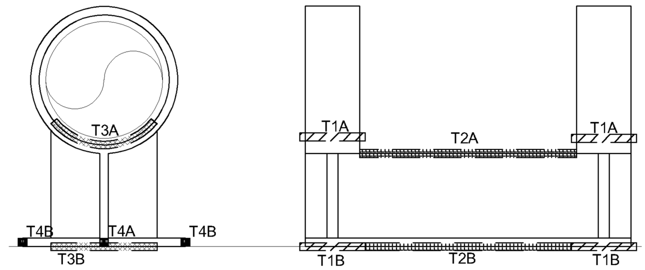



Figure 6.1: Temperature regions to determine heat transfer through pipe shoe supports

Table 6.1: Temperature on the locations indicated in figure5.1

| pipe 6" | Tpipe | T1A | T1B | T2A | T2B | T3A | T3B | T4A | T4B |
|---|---|---|---|---|---|---|---|---|---|
| standard | 0[ºC] | 1,6[ºC] | 5,8[ºC] | 4,9[ºC] | 5,8[ºC] | 1,4[ºC] | 6,0[ºC] | 6,5[ºC] | 7,0[ºC] |
| solution | 100[ºC] | 86,6[ºC] | 48,0[ºC] | 56,5[ºC] | 47,9[ºC] | 88,5[ºC] | 46,6[ºC] | 42,3[ºC] | 7,0[ºC] |
| | 300[ºC] | 256,8[ºC] | 132,5[ºC] | 159,8[ºC] | 132,2[ºC] | 263,1[ºC] | 128,0[ºC] | 114,0[ºC] | 99,2[ºC] |
| P. insu=60[mm] | 500[ºC] | 427,0[ºC] | 216,9[ºC] | 263,1[ºC] | 216,5[ºC] | 437,6[ºC] | 209,4[ºC] | 185,7[ºC] | 160,8[ºC] |

Table 6.2: Heat transfer through pipe shoe supports between the regions indicated in figure5.1

| | T1 | T2 | T3 | T4 | Total |
|---|---|---|---|---|---|
| λ | 44 | 44 | 44 | 44 | |
| L | 0,1 | 0,1 | 0,100004011 | 0,075 | |
| Surface | 0,0005 | 0,002 | 0,0015 | 0,003 | |
| 0[ºC] | -0,75[W] | -0,83[W] | -3,04[W] | -0,89[W] | -10[W] |
| 100[ºC] | 8,49[W] | 7,52[W] | 27,66[W] | 62,16[W] | 204[W] |
| 300[ºC] | 27,35[W] | 24,24[W] | 89,13[W] | 25,95[W] | 309[W] |
| 500[ºC] | 46,21[W] | 40,96[W] | 150,60[W] | 43,85[W] | 522[W] |

Using the method mentioned on the previous page the following results have been collected for the heat transfer through the different pipe support solutions. The following table shows the data for the heat transfer through the pipe shoe. The original Jacobs standard application and the two insulating solutions have been collected and presented next to each other. This provides an overview of the benefits of the insulation solutions compared to the Jacobs standard.

Table 6.3: overview of FEM generated heat transfer results

| Pipe size | Pipe Temp. | Heat transfer per support solution and insulation thickness | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Standard support shoe | | | Shoe on insulation plate | | | Disconnected pipe clamp | | |
| | | Insulation Thick. 50[mm] | Insulation Thick. 60[mm] | Insulation Thick. 70[mm] | Insulation Thick. 50[mm] | Insulation Thick. 60[mm] | Insulation Thick. 70[mm] | Insulation Thick. 50[mm] | Insulation Thick. 60[mm] | Insulation Thick. 70[mm] |
| 4 | 0 | -6[W] | -5[W] | -5[W] | -3[W] | -5[W] | -3[W] | -1[W] | 0[W] | 0[W] |
| | 100 | 51[W] | 47[W] | 47[W] | 31[W] | 43[W] | 30[W] | 6[W] | 4[W] | 3[W] |
| | 300 | 163[W] | 150[W] | 151[W] | 99[W] | 137[W] | 1454[W] | 27[W] | 12[W] | 10[W] |
| | 500 | 276[W] | 254[W] | 255[W] | 167[W] | 232[W] | 165[W] | 33[W] | 20[W] | 17[W] |
| 6 | 0 | -12[W] | -10[W] | -12[W] | -10[W] | -10[W] | -10[W] | -1[W] | -1[W] | -1[W] |
| | 100 | 112[W] | 204[W] | 114[W] | 66[W] | 97[W] | 99[W] | 8[W] | 13[W] | 13[W] |
| | 300 | 359[W] | 309[W] | 362[W] | 314[W] | 314[W] | 320[W] | 26[W] | 43[W] | 43[W] |
| | 500 | 607[W] | 522[W] | 612[W] | 531[W] | 530[W] | 540[W] | 44[W] | 72[W] | 72[W] |
| 8 | 0 | -12[W] | -11[W] | -10[W] | -8[W] | -7[W] | -4[W] | -2[W] | -1[W] | -1[W] |
| | 100 | 275[W] | 103[W] | 90[W] | 75[W] | 66[W] | 40[W] | 16[W] | 7[W] | 12[W] |
| | 300 | 357[W] | 333[W] | 291[W] | 241[W] | 211[W] | 130[W] | 52[W] | 23[W] | 38[W] |
| | 500 | 604[W] | 562[W] | 489[W] | 407[W] | 357[W] | 220[W] | 87[W] | 39[W] | 63[W] |
| 10 | 0 | -11[W] | -11[W] | -10[W] | -7[W] | -7[W] | -4[W] | -1[W] | -1[W] | -1[W] |
| | 100 | 104[W] | 105[W] | 101[W] | 68[W] | 69[W] | 68[W] | 7[W] | 7[W] | 5[W] |
| | 300 | 336[W] | 337[W] | 325[W] | 218[W] | 221[W] | 0[W] | 24[W] | 0[W] | 17[W] |
| | 500 | 568[W] | 570[W] | 321[W] | 368[W] | 374[W] | 362[W] | 40[W] | 39[W] | 29[W] |

| Pipe size | Pipe temp. | Continuation: Heat transfer per support solution and insulation thickness | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Standard support shoe | | | Shoe on insulation plate | | | Disconnected pipe clamp | | |
| | | Insulation Thick. 50[mm] | Insulation Thick. 60[mm] | Insulation Thick. 70[mm] | Insulation Thick. 50[mm] | Insulation Thick. 60[mm] | Insulation Thick. 70[mm] | Insulation Thick. 50[mm] | Insulation Thick. 60[mm] | Insulation Thick. 70[mm] |
| 12 | 0 | -15[W] | | -14[W] | -12[W] | -11[W] | -10[W] | -1[W] | -1[W] | -1[W] |
| | 100 | 142[W] | | 131[W] | 112[W] | 104[W] | 93[W] | 11[W] | 9[W] | 8[W] |
| | 300 | 459[W] | | 423[W] | 0[W] | 335[W] | x | x | x | x |
| | 500 | 775[W] | | 715[W] | 606[W] | 291[W] | 504[W] | 59[W] | 48[W] | 41[W] |
| 14 | 0 | -12[W] | -12[W] | -13[W] | -10[W] | -10[W] | -10[W] | -1[W] | | -1[W] |
| | 100 | 120[W] | 114[W] | 122[W] | 97[W] | 100[W] | 99[W] | 11[W] | | 7[W] |
| | 300 | x | 367[W] | | x | x | 319[W] | 0[W] | | 0[W] |
| | 500 | 653[W] | 619[W] | 665[W] | 529[W] | 545[W] | 539[W] | 57[W] | | 41[W] |
| 16 | 0 | -15[W] | -14[W] | -15[W] | -11[W] | 3[W] | -10[W] | 0[W] | -1[W] | -1[W] |
| | 100 | 144[W] | 136[W] | 147[W] | 108[W] | 196[W] | 98[W] | 3[W] | 7[W] | 6[W] |
| | 300 | x | x | 473[W] | x | x | x | 9[W] | x | 20[W] |
| | 500 | 782[W] | 738[W] | 800[W] | 590[W] | 972[W] | 532[W] | 15[W] | 40[W] | 34[W] |
| 20 | 0 | -18[W] | -17[W] | -18[W] | -17[W] | -11[W] | -12[W] | -1[W] | -1[W] | -1[W] |
| | 100 | 172[W] | 161[W] | 175[W] | 162[W] | 107[W] | 114[W] | 10[W] | 9[W] | 9[W] |
| | 300 | x | x | x | x | x | x | 31[W] | 27[W] | 28[W] |
| | 500 | 938[W] | 877[W] | 952[W] | 882[W] | 585[W] | 622[W] | 53[W] | 46[W] | 47[W] |

# 7. Testing predicted values of finite element calculations

## 7.1. Test case 1: steam line near furnace

Situation: The pipe is at the edge of a furnace. The Ambient temperature is high. No exact data is available but the ambient temperature is estimated at 45[ºC] due to the heat coming from the furnace.
The pipe is 16[Inch] in diameter and wrapped in 100[mm] insulation. At the location of the pipe shoe support the insulation thickness is reduced to 70[mm]. The measured temperatures will be therefore compared with the result of FEM calculations for 16[Inch] standard support shoes.

Due to limitations few measurements could be performed

| Measurement locations | FEM predicted temperature | Measured temperature | Inaccuracy FEM |
|---|---|---|---|
| **T6** | 220[ºC] | 200[ºC] | +10 % |
| **T10** | 135[ºC] | 130[ºC] | -4 % |
| **T11** | 74[ºC] | 100[ºC] | -24 % |

Due to the radiation of the furnace the temperature of steel is higher than calculated, as radiation is not included in the FEM calculations. A 10% difference on the pipe shoe can be expected due to the inaccuracy of measurements.

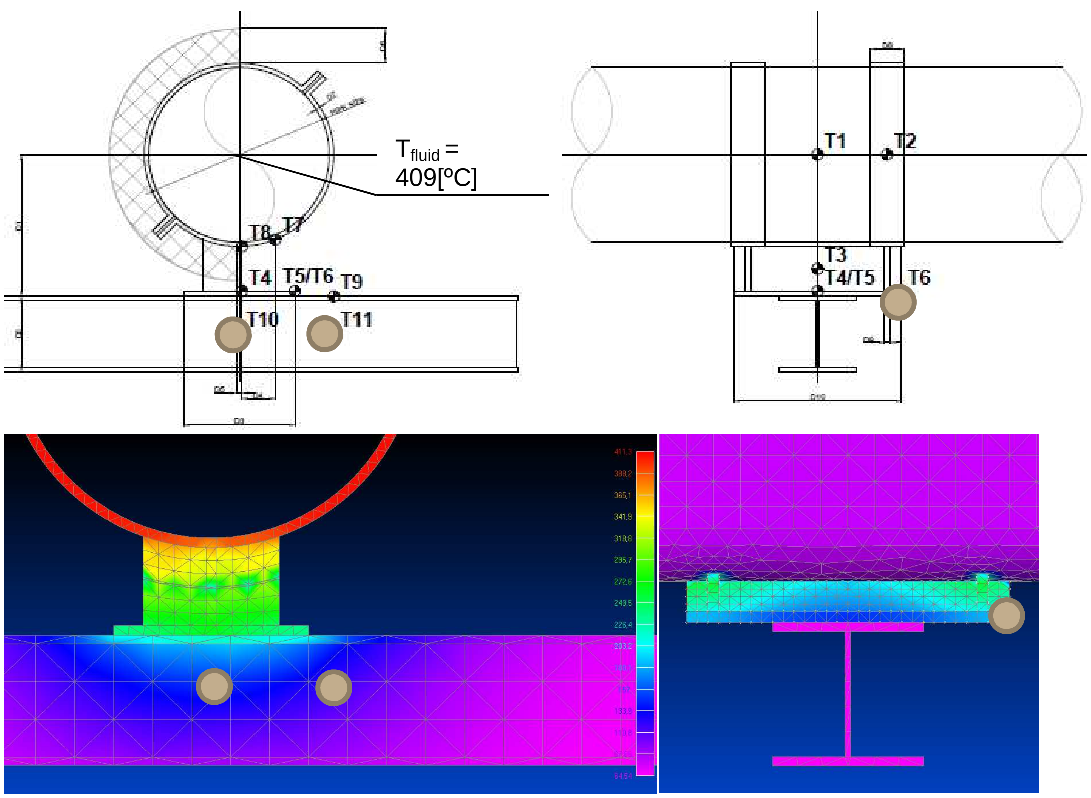



Figure 7.1: Graphical representation of locations measured

## 7.2. Test case 2

Situation: The pipe is located on the outer edge of the plant and is exposed to winds. On the day of the measurements there was a relatively strong wind blowing.
The pipe is 6[Inch] in diameter and wrapped in 60[mm] insulation. The measured temperatures will be therefore compared with the result of FEM calculations for 6[Inch] standard support shoes.

Due to limitations a few measurements could be performed

| Measurement locations | FEM predicted temperature | Measured temperature | Inaccuracy FEM |
|---|---|---|---|
| **T3** | 75[ºC] | 86[ºC] | +13% |
| **T6** | 80[ºC] | 90[ºC] | +11% |
| **T10** | 40[ºC] | 35[ºC] | +14% |
| **T11** | 36[ºC] | 32[ºC] | +12% |

The differences between the predicted temperatures by the FEM calculations and measured temperatures are within the expected range.

Figure 7.2: Photos of measurement situation

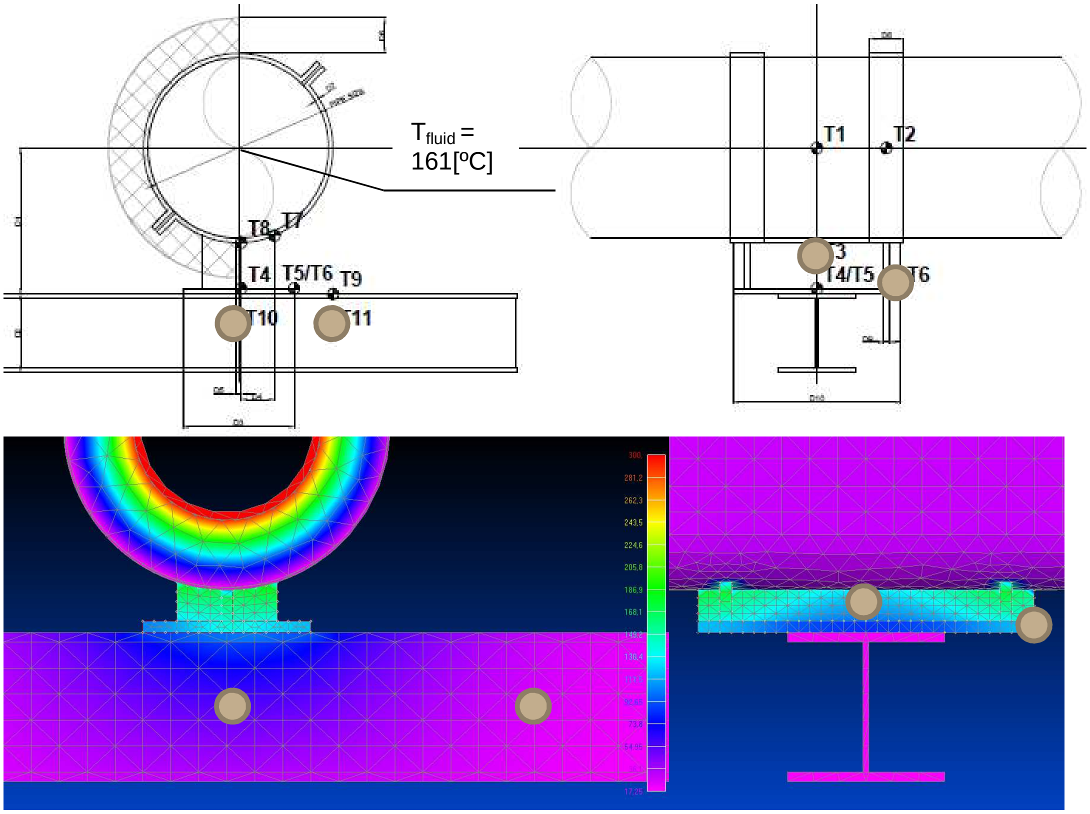



Figure 7.3: Graphical representation of locations measured

# 8. Analysis

## 8.1. Analysis of the influence of the pipe temperature

Because the radiation has been left out of the analysis models the temperature has a linear correlation with the heat transfer through the pipe support. This was to be expected as the heat flow through convection and conduction are both linear functions.

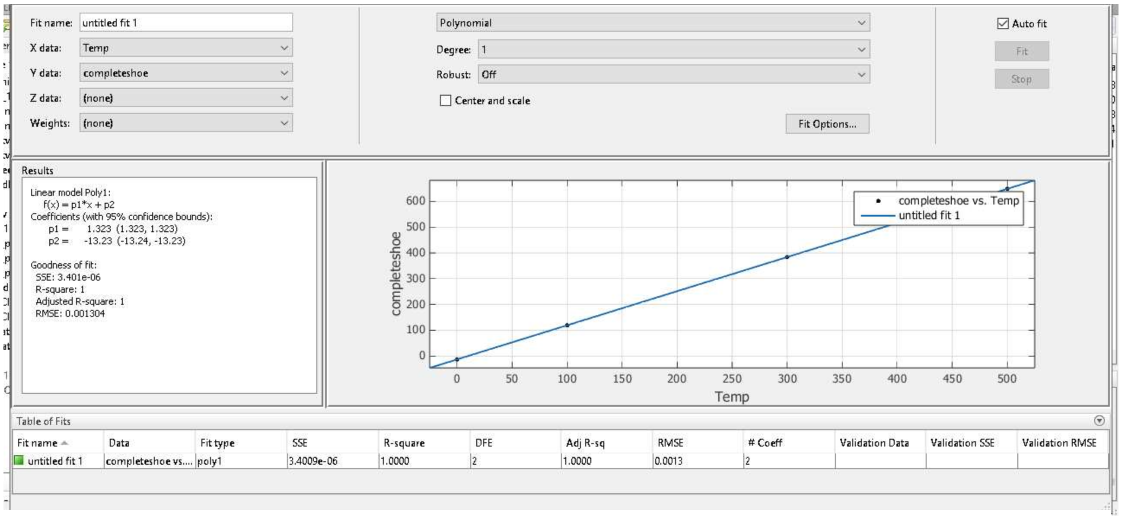



Figure 8.1: Matlab curve fitting applied on a 4"pipe with 50[mm] insulation and a temperature range from 0 to 500[ºC]

## 8.2. Comparing FEM results to 1D analytical calculations

| Comparing FEM result to one dimensional analytical result<br>Standard shoe support 50[mm] | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pipe | 4[Inch] | | | 6[Inch] | | | 8[Inch] | | | 10[Inch] | | |
| Temp. | Theory | FEM | ΔΦ | Theory | FEM | ΔΦ | Theory | FEM | ΔΦ | Theory | FEM | ΔΦ |
| 0[ºC] | -6[W] | -6[W] | 11% | -12[W] | -12[W] | 4% | -13[W] | -12[W] | 10% | -13[W] | -11[W] | 21% |
| 100[ºC] | 37[W] | 51[W] | 27% | 75[W] | 112[W] | 33% | 78[W] | 275[W] | 72% | 78[W] | 104[W] | 25% |
| 300[ºC] | 123[W] | 163[W] | 25% | 250[W] | 359[W] | 30% | 261[W] | 357[W] | 27% | 261[W] | 336[W] | 22% |
| 500[ºC] | 209[W] | 276[W] | 24% | 425[W] | 607[W] | 30% | 443[W] | 604[W] | 27% | 443[W] | 568[W] | 22% |

| Comparing FEM result to one dimensional analytical result<br>Standard shoe support 50[mm] | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pipe | 12[Inch] | | | 14[Inch] | | | 16[Inch] | | | 20[Inch] | | |
| Temp. | Theory | FEM | ΔΦ | Theory | FEM | ΔΦ | Theory | FEM | ΔΦ | Theory | FEM | ΔΦ |
| 0[ºC] | -16[W] | -15[W] | 10% | -16[W] | -12[W] | 30% | -21[W] | -15[W] | 39% | -25[W] | -18[W] | 41% |
| 100[ºC] | 100[W] | 142[W] | 30% | 100[W] | 120[W] | 17% | 131[W] | 144[W] | 9% | 161[W] | 172[W] | 6% |
| 300[ºC] | 332[W] | 459[W] | 28% | 332[W] | x | x | 435[W] | 0[W] | | 535[W] | x | x |
| 500[ºC] | 564[W] | 775[W] | 27% | 564[W] | 653[W] | 14% | 739[W] | 782[W] | 6% | 908[W] | 938[W] | 3% |

| Comparing FEM result to one dimensional analytical result<br>Standard shoe support 60[mm] | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pipe | 4[Inch] | | | 6[Inch] | | | 8[Inch] | | | 10[Inch] | | |
| Temp. | Theory | FEM | ΔΦ | Theory | FEM | ΔΦ | Theory | FEM | ΔΦ | Theory | FEM | ΔΦ |
| 0[ºC] | -6[W] | -5[W] | 32% | -12[W] | -10[W] | 21% | -13[W] | -11[W] | 16% | -13[W] | -11[W] | 19% |
| 100[ºC] | 35[W] | 47[W] | 24% | 72[W] | 204[W] | 35% | 76[W] | 103[W] | 27% | 76[W] | 105[W] | 28% |
| 300[ºC] | 118[W] | 150[W] | 21% | 242[W] | 309[W] | 78% | 252[W] | 333[W] | 24% | 252[W] | 337[W] | 25% |
| 500[ºC] | 201[W] | 254[W] | 21% | 411[W] | 522[W] | 79% | 429[W] | 562[W] | 24% | 429[W] | 570[W] | 25% |

| Comparing FEM result to one dimensional analytical result<br>Standard shoe support 60[mm] | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pipe | 12[Inch] | | | 14[Inch] | | | 16[Inch] | | | 20[Inch] | | |
| Temp. | Theory | FEM | ΔΦ | Theory | FEM | ΔΦ | Theory | FEM | ΔΦ | Theory | FEM | ΔΦ |
| 0[ºC] | -16[W] | | | -16[W] | -12[W] | 35% | -21[W] | -14[W] | 45% | -25[W] | -17[W] | 50% |
| 100[ºC] | 96[W] | | | 96[W] | 114[W] | 15% | 127[W] | 136[W] | 6% | 157[W] | 161[W] | 3% |
| 300[ºC] | 321[W] | | | 321[W] | 367[W] | 12% | 422[W] | x | x | 520[W] | x | x |
| 500[ºC] | 546[W] | | | 546[W] | 619[W] | 12% | 718[W] | 738[W] | 3% | 883[W] | 877[W] | 1% |

| Comparing FEM result to one dimensional analytical result<br>Standard shoe support 70[mm] | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pipe | 4[Inch] | | | 6[Inch] | | | 8[Inch] | | | 10[Inch] | | |
| Temp. | Theory | FEM | ΔΦ | Theory | FEM | ΔΦ | Theory | FEM | ΔΦ | Theory | FEM | |
| 0[ºC] | -6[W] | -5[W] | 16% | -12[W] | -12[W] | 2% | -13[W] | -10[W] | 33% | -13[W] | -10[W] | 22% |
| 100[ºC] | 34[W] | 47[W] | 28% | 70[W] | 114[W] | 39% | 73[W] | 90[W] | 19% | 73[W] | 101[W] | 28% |
| 300[ºC] | 114[W] | 151[W] | 25% | 234[W] | 362[W] | 35% | 244[W] | 291[W] | 16% | 244[W] | 325[W] | 25% |
| 500[ºC] | 194[W] | 255[W] | 24% | 397[W] | 612[W] | 35% | 415[W] | 489[W] | 15% | 415[W] | 321[W] | 29% |

| Comparing FEM result to one dimensional analytical result<br>Standard shoe support 70[mm] | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pipe | 12[Inch] | | | 14[Inch] | | | 16[Inch] | | | 20[Inch] | | |
| Temp. | Theory | FEM | ΔΦ | Theory | FEM | ΔΦ | Theory | FEM | ΔΦ | Theory | FEM | ΔΦ |
| 0[ºC] | -16[W] | -14[W] | 16% | -16[W] | -13[W] | 25% | -20[W] | -15[W] | 32% | -25[W] | -18[W] | 37% |
| 100[ºC] | 93[W] | 131[W] | 29% | 93[W] | 122[W] | 24% | 123[W] | 147[W] | 16% | 152[W] | 175[W] | 13% |
| 300[ºC] | 311[W] | 423[W] | 26% | 311[W] | x | x | 410[W] | 473[W] | 13% | 506[W] | x | x |
| 500[ºC] | 529[W] | 715[W] | 26% | 529[W] | 665[W] | 20% | 697[W] | 800[W] | 13% | 859[W] | 952[W] | 10% |

When we look at the average difference between the FEM calculation and the theoretical calculations the error margin lays between 20% and 35%. The inaccuracy is largest at the 6 and 8 inch pipe shoes. And stabilize as when comparing the larger pipe sizes.

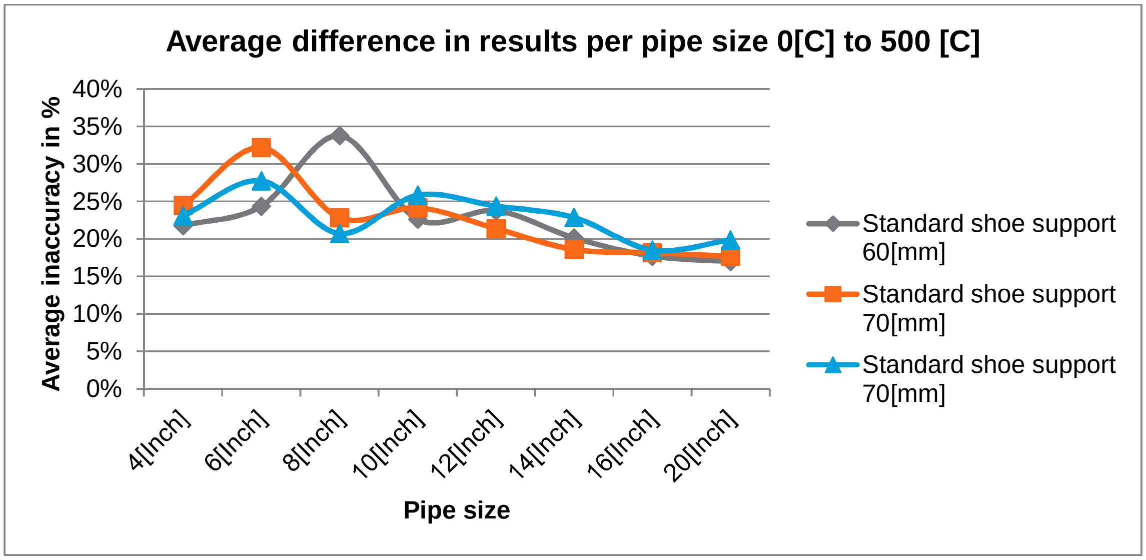



**Figure 8.2: The difference between the analytical and FEM results**

When we limit our reach to the temperature range from 100[ºC] to 500[ºC], we see a change in the curve describing the differences between the two calculation approaches. Again we see that the largest difference lay at 6 and 8 inch pipe shoes. Only now the difference drops to below 15% as way move through the graphs to the 20 inch pipe shoes.

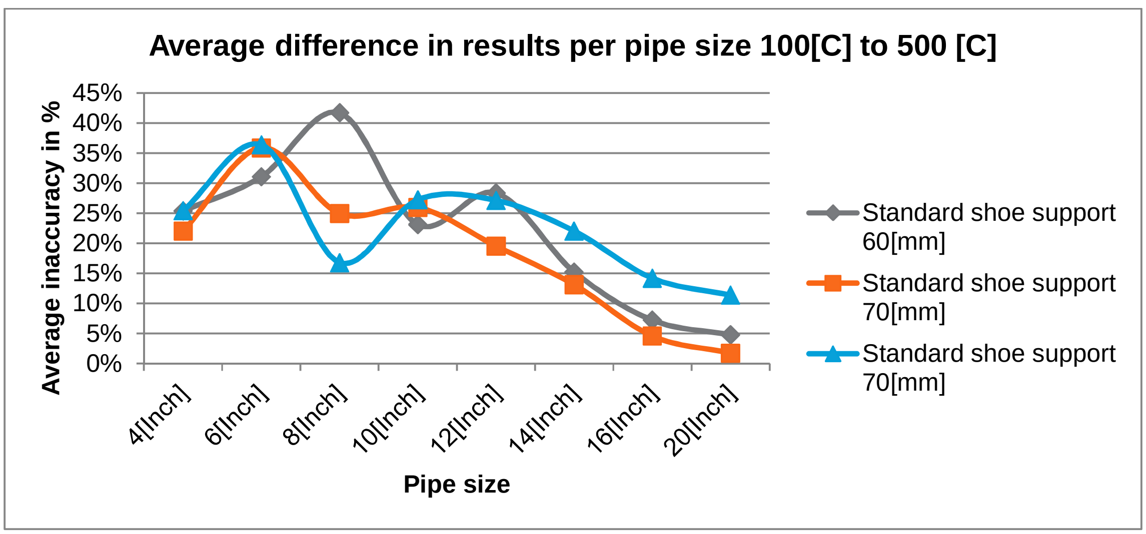



**Figure 8.3: The difference between the analytical and FEM results**

Some differences are to be expected as the actual heat transfer is a 3 dimensional problem. A one dimensional analytical calculation calculates only one of three directions of heat transfer.

### 8.2.1. Equations following the Matlab analysis

The following table presents the equations found that describe the individual support solutions. These equations are the basis of the heat transfer calculation work file.

**Table 8.1: Equations to calculate heat transfer per support**

| Pipe Size | Standard pipe shoe support $\Phi = A*T-B$ | | | | | |
|---|---|---|---|---|---|---|
| | Insu 50 | | Insu 60 | | Insu 70 | |
| | A | B | A | B | A | B |
| 4 | 0,56242 | -5,62421 | 0,517984 | -4,66187 | 0,520603 | -5,20596 |
| 6 | 1,239012 | -11,9752 | 1,064955 | -10,1791 | 1,245402 | -11,9379 |
| 8 | 1,231225 | -11,8456 | 1,14781 | -11,0441 | 0,998458 | -9,57137 |
| 10 | 1,159388 | -10,7604 | 1,163429 | -10,8297 | 0,551772 | -10,4345 |
| 12 | 1,582592 | -14,7243 | | | 1,459151 | -13,6122 |
| 14 | 1,33196 | -12,4684 | 1,264128 | -11,8484 | 1,356936 | -12,6915 |
| 16 | 1,596702 | -15,0231 | 1,506621 | -14,1732 | 1,631999 | -15,4865 |
| 20 | 1.91377 | -17,8144 | 1,789884 | -16,6783 | 1,942033 | -18,0356 |
| **Pipe Size** | **Pipe shoe with a disconnected pipe clamp $\Phi = A*T-B$** | | | | | |
| | Insu 50 | | Insu 60 | | Insu 70 | |
| | A | B | A | B | A | B |
| 4 | 0,067546 | -0,66871 | 0,040968 | -0,4056 | 0,034271 | -0,33928 |
| 6 | 0,089016 | -0,88126 | 0,147947 | -1,46468 | 0,147133 | -1,45662 |
| 8 | 0,177679 | -1,75902 | 0,079239 | -0,78446 | 0,129391 | -1,2809 |
| 10 | 0,081515 | -0,80699 | 0,080538 | -0,7973 | 0,058639 | -0,58052 |
| 12 | 0,120577 | -1,1938 | 0,098613 | -0,97626 | 0,084175 | -0,83344 |
| 14 | 0,116677 | -1,15507 | 0.061632 | -0.88717 | 0,082796 | -0,81963 |
| 16 | 0,030814 | -0,30494 | 0,080618 | -0,79807 | 0,068749 | -0,68062 |
| 20 | 0,107982 | -1,06902 | 0,094521 | -0,93499 | 0,095777 | -0,94743 |
| **Pipe Size** | **Pipe shoe on an insulation plate $\Phi = A*T-B$** | | | | | |
| | Insu 50 | | Insu 60 | | Insu 70 | |
| | A | B | A | B | A | B |
| 4 | 0,341256 | -3,41251 | 0,47378 | -4,69134 | 0,336873 | -3,36864 |
| 6 | 1,162151 | -10,3921 | 1,081381 | -10,2755 | 1,102274 | -10,4769 |
| 8 | 0,83118 | -7,91409 | 0,728868 | -6,93107 | 0,448166 | -4,27985 |
| 10 | 0,750898 | -6,91363 | 0,762371 | -7,00092 | 0,733961 | -4,45381 |
| 12 | 1,236212 | -11,6489 | 0,468682 | -10,8572 | 1,028067 | -9,72093 |
| 14 | 1,078898 | -10,2898 | 1,112609 | -10,4886 | 1,099852 | -10,3403 |
| 16 | 1,204035 | -11,1443 | 1,940692 | 2,577134 | 1,08553 | -10,0269 |
| 20 | 1,799368 | -16,69 | 1,192885 | -11,2062 | 1,270225 | -11,908 |

# 9. Calculation work file

The work file will be constructed to provide insight in the heat transfer and related costs for the analyzed pipe shoe supports. The two analyzed insulation solutions will be compared to the standard pipe shoes. The comparison will show the investment cost and possible savings. The effectiveness of an insulated pipe shoe solution can be determined by comparing the total saving over the life time of the pipe and the breakeven point of the investment.

The output will be based on the heat transfer data generated through FEM calculations.

## 9.1. Support solution related output

The output and data will be presented for all three support solutions simultaneously and graphs will visualize the comparisons. The output data will be based on entered pipe size and process conditions.

Table 9.1: Overview of output per support type

| Output Cases | | |
|---|---|---|
| **Standard pipe shoe support** | **Disconnected pipe clamp solution** | **Pipe shoe on insulation plate** |
| **Heat transfer** | **Heat transfer** | **Heat transfer** |
| Per shoe | Per shoe | Per shoe |
| per total number of shoes | per total number of shoes | per total number of shoes |
| **Energy lost per set number of years** | **Energy lost per set number of years** | **Energy lost per set number of years** |
| Per shoe | Per shoe | Per shoe |
| per total number of shoes | per total number of shoes | per total number of shoes |
| **Financial implications** | **Financial implications** | **Financial implications** |
| Per shoe | Per shoe | Per shoe |
| per total number of shoes | per total number of shoes | per total number of shoes |
| **CO2 output** | **CO2 output** | **CO2 output** |
| per total number of shoes | per total number of shoes | per total number of shoes |

## 9.2. Heat transfer output per size and temperature

The FEM generated data has been analyzed and can describe any given support solution with the equation: $\Phi_h(T) = A * T + B$. Based on the user input the appropriate equation is selected and the heat transfer calculated.

- $\Phi_h(T) = A * T + B$
    - $\mathrm{A} = \mathrm{d}\Phi_h/dT = (\Phi_h(500) - \Phi_h(100))/400$
    - $B = \Phi_h(0)$

## 9.3. Financial analysis output

### 9.3.1. Investment costs

The investment costs are based on Jacobs's internal estimating data. The material cost is calculated through a cost per unit ratio. On top of the material cost the labor costs are estimated against an hour rate. The investment cost can be seen as an absolute value per support solution or as an additional investment on top of the standard support solution, as a support solution will always be required. The results are summarized in the table below.

The investment costs are divined as the sum of material costs and installation costs.

- $\text{Price} = \sum(\text{M} * \text{u} + \text{C} * \text{t})$
    - o $\text{M} = \text{Mass [kg]}$
    - o $\text{u} = \text{unit prive}[€/\text{kg}]$
    - o $\text{C} = \text{Contracter hour rate}\left[{}^{€}/_{h}\right]$
    - o $\text{t} = \text{installation time [h]}$
- or equivalent based on the applicable unit price of material.

**Table 9.2: Calculation sheet to determine the investment cost per pipe support solution (Appendix III)**

**Investment Costs for pipe shoe solutions**

Number of supports reviewed **100**

| | | | 4[Inch] | 6[Inch] | 8[Inch] | 10[Inch] | 12[Inch] | 14[Inch] | 16[Inch] | 20[Inch] |
|---|---|---|---|---|---|---|---|---|---|---|
| **Standard pipe shoe support** | **weight per shoe per pipe size h=100** | | 8[kg] | 13[kg] | 14[kg] | 18[kg] | 22[kg] | 24[kg] | 36[kg] | 44[kg] |
| | **Price @ Steel cost** | 12[€/kg] | € 10.080 | € 15.600 | € 17.160 | € 21.120 | € 26.280 | € 28.560 | € 43.200 | € 52.800 |
| | **Standard shoe support installation time** | | 1,00[h] | 1,10[h] | 1,20[h] | 1,30[h] | 1,40[h] | 1,50[h] | 1,60[h] | 1,70[h] |
| | **Standard shoe support installating cost** | 40[€/h] | € 4.000 | € 4.400 | € 4.800 | € 5.200 | € 5.600 | € 6.000 | € 6.400 | € 6.800 |
| | **Standard shoe support** | Total | **€ 14.080** | **€ 20.000** | **€ 21.960** | **€ 26.320** | **€ 31.880** | **€ 34.560** | **€ 49.600** | **€ 59.600** |
| **Disconnected pipe clamp** | **weight of shoe for disconnected clamp** | | 23[kg] | 37[kg] | 45[kg] | 53[kg] | 62[kg] | 66[kg] | 75[kg] | 91[kg] |
| | **Price @ Steel cost** | 12[€/kg] | € 27.083 | € 44.962 | € 53.971 | € 63.547 | € 73.967 | € 79.588 | € 90.008 | € 109.437 |
| | **Surface monolux m2 per size** | | 0,26[M2] | 0,36[M2] | 0,46[M2] | 0,56[M2] | 0,66[M2] | 0,72[M2] | 0,81[M2] | 1,00[M2] |
| | **monolux d=50.8mm round cost** | 289[€/m2] | € 7.579 | € 10.517 | € 13.281 | € 16.219 | € 18.983 | € 20.707 | € 23.471 | € 28.999 |
| | **disconnected support installation time** | | 1,50[h] | 1,60[h] | 1,70[h] | 1,80[h] | 1,90[h] | 2,00[h] | 2,10[h] | 2,20[h] |
| | **Disconnected pipe clamp installation cost** | 40[€/h] | € 6.000 | € 6.400 | € 6.800 | € 7.200 | € 7.600 | € 8.000 | € 8.400 | € 8.800 |
| | **Disconnected pipe clamp** | Total | **€ 40.661** | **€ 61.878** | **€ 74.051** | **€ 86.965** | **€ 100.549** | **€ 108.295** | **€ 121.879** | **€ 147.235** |
| | **Additional investment cost compared standard pipe shoe support** | | **€ 26.581** | **€ 47.798** | **€ 59.971** | **€ 72.885** | **€ 86.469** | **€ 94.215** | **€ 107.799** | **€ 133.155** |
| **Shoe on insulation plate** | **weight per shoe per pipe size h=100** | | 8[kg] | 13[kg] | 14[kg] | 18[kg] | 22[kg] | 24[kg] | 36[kg] | 44[kg] |
| | **Price @ Steel cost** | 12[€/kg] | € 10.080 | € 15.600 | € 17.160 | € 21.120 | € 26.280 | € 28.560 | € 43.200 | € 52.800 |
| | **monolux m2 per size** | | 0,03[M2] | 0,05[M2] | 0,05[M2] | 0,05[M2] | 0,06[M2] | 0,06[M2] | 0,08[M2] | 0,09[M2] |
| | **monolux d=50.8mm cost** | 289[€/m2] | € 866 | € 1.299 | € 1.299 | € 1.299 | € 1.732 | € 1.732 | € 2.165 | € 2.598 |
| | **Shoe on insulation plate installation time** | | 2,00[h] | 2,00[h] | 2,00[h] | 2,10[h] | 2,10[h] | 2,10[h] | 2,20[h] | 2,20[h] |
| | **Shoe on insulation plate installation cost** | 40[€/h] | € 8.000 | € 8.000 | € 8.000 | € 8.400 | € 8.400 | € 8.400 | € 8.800 | € 8.800 |
| | **Shoe on insulation plate** | Total | **€ 18.946** | **€ 24.899** | **€ 26.459** | **€ 30.819** | **€ 36.412** | **€ 38.692** | **€ 54.165** | **€ 64.198** |
| | **Relative investment against standard pipe shoe support** | | **€ 4.865** | **€ 10.818** | **€ 12.378** | **€ 16.738** | **€ 22.331** | **€ 24.611** | **€ 40.084** | **€ 50.117** |

### 9.3.2. Operating costs

The heating of fluids and or gasses consumes energy. The energy has to bought or generated. The heating can be done to increase the temperature (e.g.in a furnace) or to maintain a set temperature over the length of a pipe. Examples of commonly used heat transferring equipment are:

- Furnace
- Heat exchanger
  - Tubular
  - Plate type
- Heat tracing
  - Electrical tracing
  - Steam tracing

Typically the heat is generated by burning fuels or with electrical power. Within this assignment natural gas and electricity are included.

The operating costs are determined as the cost per year extrapolated over time. No additional costs for inspection are included for the insulation solutions, because the support solutions are static and non-corrosive.

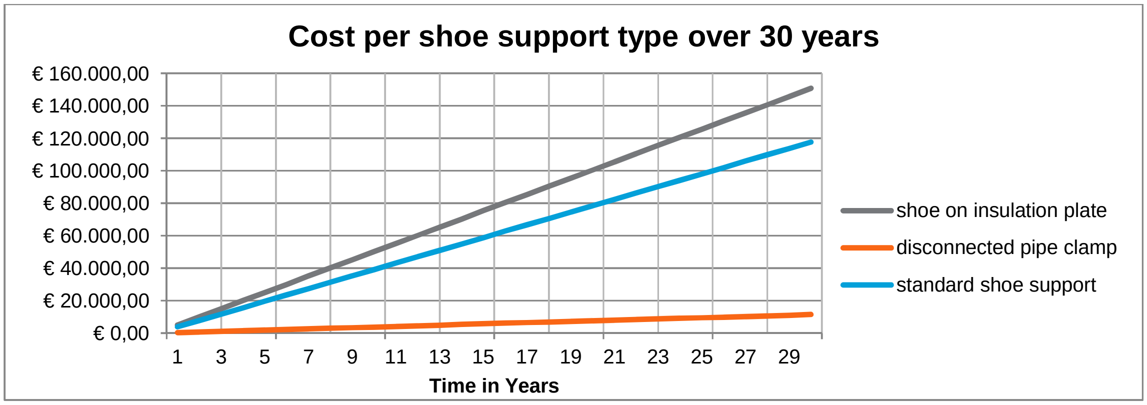



Figure 9.1: Cumulative cost over time

### 9.3.3. Return time of investment and total profit

If an investment will be made is largely determined by the return time of investment and total profit. The return of investment time is determined as the investment divided by the yearly savings. The graph shows the breakeven point as the cross-section of the total investment and the savings.

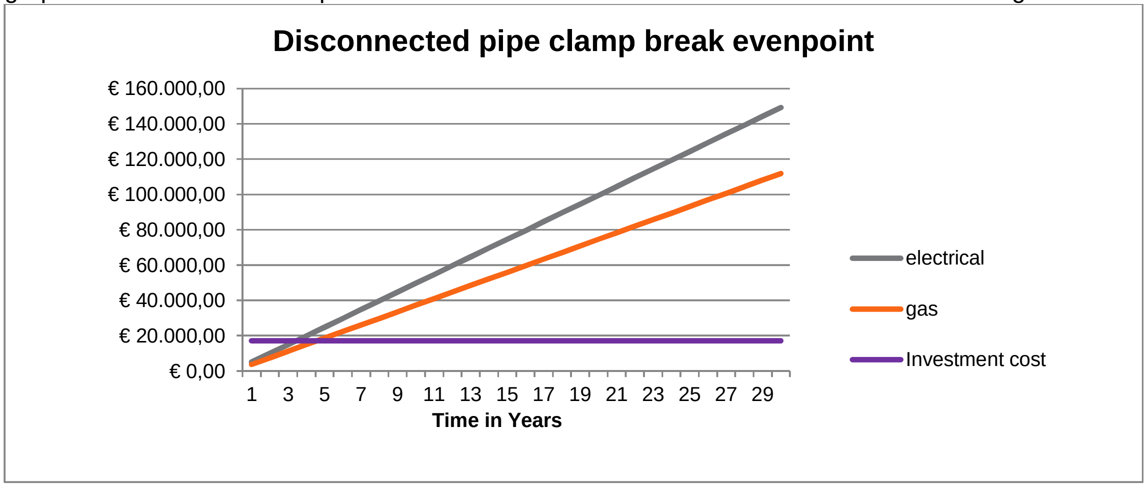



Figure 9.2: Intersection between the investment cost and the cumulative savings over time

### 9.3.4. Input and output sheet

To give a quick overview of the energy losses and financial implications all information applicable to the assessed pipe system are summarized on an overview sheet.


Figure 9.3: Input and overview sheet (Appendix II: Excel work file input sheet)

## 10. Example scenarios

The work file incorporates 8 different pipe sizes with three pipe insulation thicknesses, three supporting solutions, a range of temperatures between 0[ºC] and 500[ºC] and is dependent on the process conditions of the fluid. Because of this it is impossible to formulate a standard formulation for the financial analysis. There for the workings of the work file and the possible output will be further clarified through two possible scenarios

### 10.1. Example scenario 1: 12[Inch] pipe, steam at 300[ºC]

Scenario description: As part of a project a corroded steam line needs to be replaced. The existing pipe is 12[Inch], has a total length of 150[m] and is supported by 25 shoe supports. And the operating temperature is set to 300[ºC].

#### 10.1.1. Input:

The following scenario specific data needs to be entered into the work file:

- Operating temperature = 300[ºC]
- Specific heat @ 15[Bar] = 1664[J/kgK]
- Average flow speed = 12[m/s]
- Pipe size = 12[Inch]
- Schedule = Standard
- Pipe Insulation thickness = 70[mm]
- Expected life time = 20 [Years]
- Length of pipe = 150 [m]
- Number of shoes = 25 [Pce]

### 10.1.2. Output

Based on the input data the following results are returned by the calculations.

**Standard pipe shoe support**

| Power Balance | |
|---|---|
| Mean Power Loss per Shoe | 421.79[W] |
| Total Power Loss Through Shoes | 10569.83[W] |
| **Energy balance per 20 year(s)** | |
| Mean Energy Loss per Shoe | 74.07[MWh] |
| Total Energy Loss Through Shoes | 1851.83[MWh] |
| **Costs and outputs related to pipe Shoes per 20 year(s)** | |
| Energy Price Electricity | 57.00 [€/MWh] |
| Consumed Cost Electricity | 105554.53 [€] |
| Energy Price Gas | 11.86 [€/GJ] |
| Consumed Cost Gas [€] | 83255.33 [€] |
| **CO2 output related to pipe Shoes per 20 year(s)** | |
| Expelled CO2 (electrical based) | 23171*10e3[kg] |
| Expelled CO2 (gas based) | 24390*10e3[kg] |

**Disconnected pipe clamp (shoe support)**

| Power Balance | |
|---|---|
| Mean Power Loss per Shoe | 24.34[W] |
| Total Power Loss Through Shoes | 608.54[W] |
| **Energy balance per 20 year(s)** | |
| Mean Energy Loss per Shoe | 4.26[MWh] |
| Total Energy Loss Through Shoes | 106.62[MWh] |
| **Costs and outputs related to pipe Shoes per 20 year(s)** | |
| Energy Price Electricity | 57.00 [€/MWh] |
| Consumed Cost Electricity | 6077.15 [€] |
| Energy Price Gas | 11.86 [€/GJ] |
| Consumed Cost Gas [€] | 4793.31 [€] |
| **CO2 output related to pipe Shoes per 20 year(s)** | |
| Expelled CO2 (electrical based) | 1334*10e3[kg] |
| Expelled CO2 (gas based) | 1404*10e3[kg] |

**Shoe support on insulation plate**

| Power Balance | |
|---|---|
| Mean Power Loss per Shoe | 297.76[W] |
| Total Power Loss Through Shoes | 7443.88[W] |
| **Energy balance per 20 year(s)** | |
| Mean Energy Loss per Shoe | 52.17[MWh] |
| Total Energy Loss Through Shoes | 1304.17[MWh] |
| **Costs and outputs related to pipe Shoes per 20 year(s)** | |
| Energy Price Electricity | 57.00 [€/MWh] |
| Consumed Cost Electricity | 74337.52 [€] |
| Energy Price Gas | 11.86 [€/GJ] |
| Consumed Cost Gas [€] | 58633.15 [€] |
| **CO2 output related to pipe Shoes per 20 year(s)** | |
| Expelled CO2 (electrical based) | 16318*10e3[kg] |
| Expelled CO2 (gas based) | 17177*10e3[kg] |

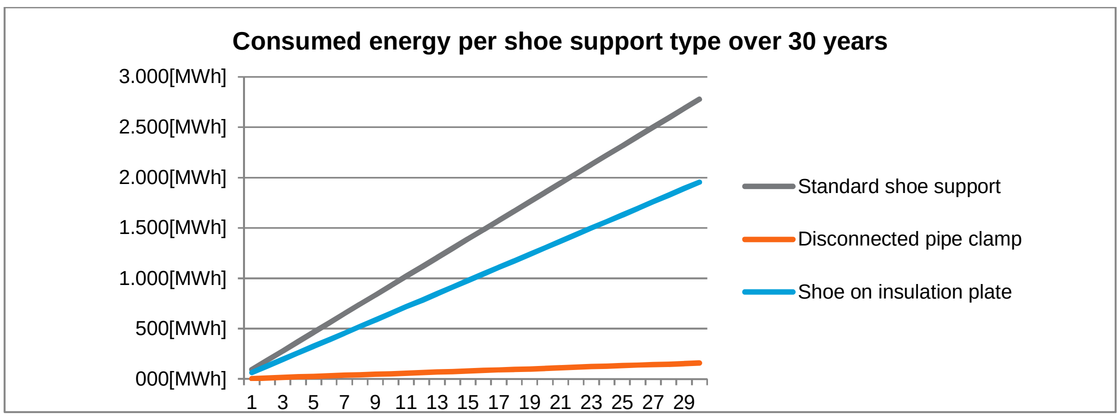



**Figure 10.1: Cumulative energy consumption**

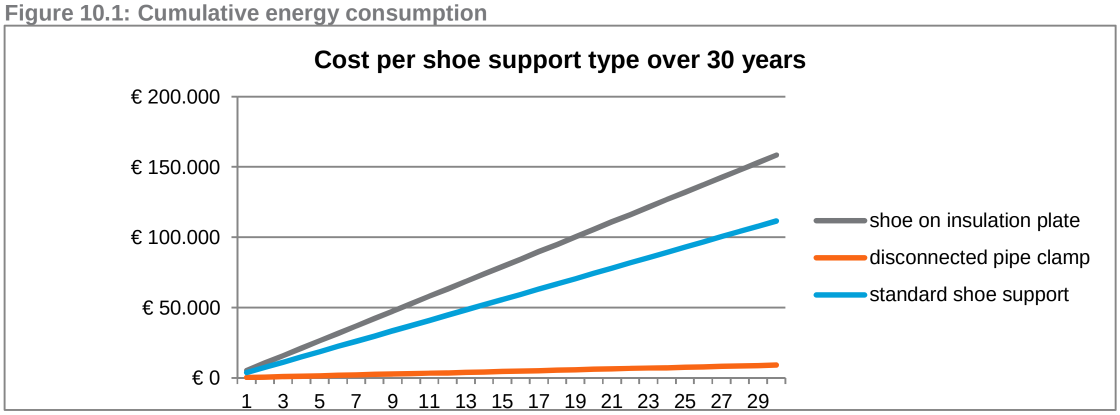



**Figure 10.2: Cumulative cost**

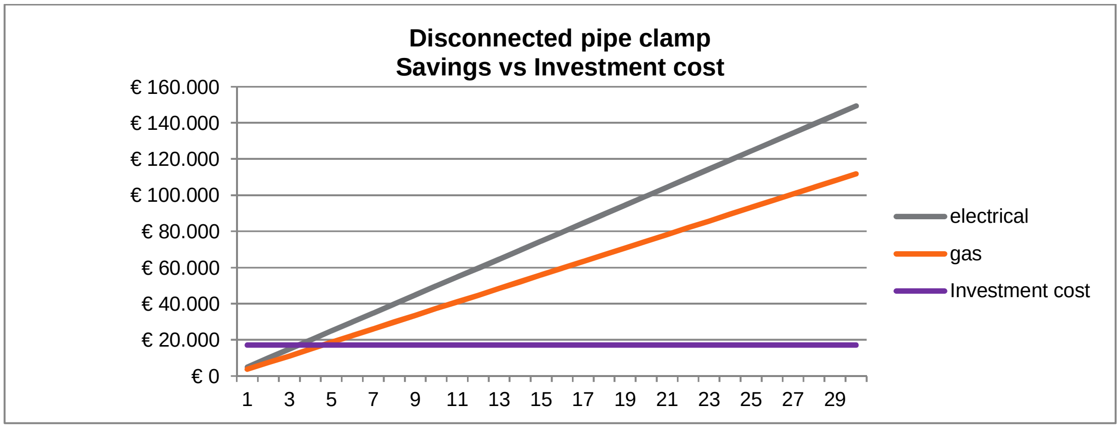



**Figure 10.3: Intersection between the investment cost and the cumulative savings over time**

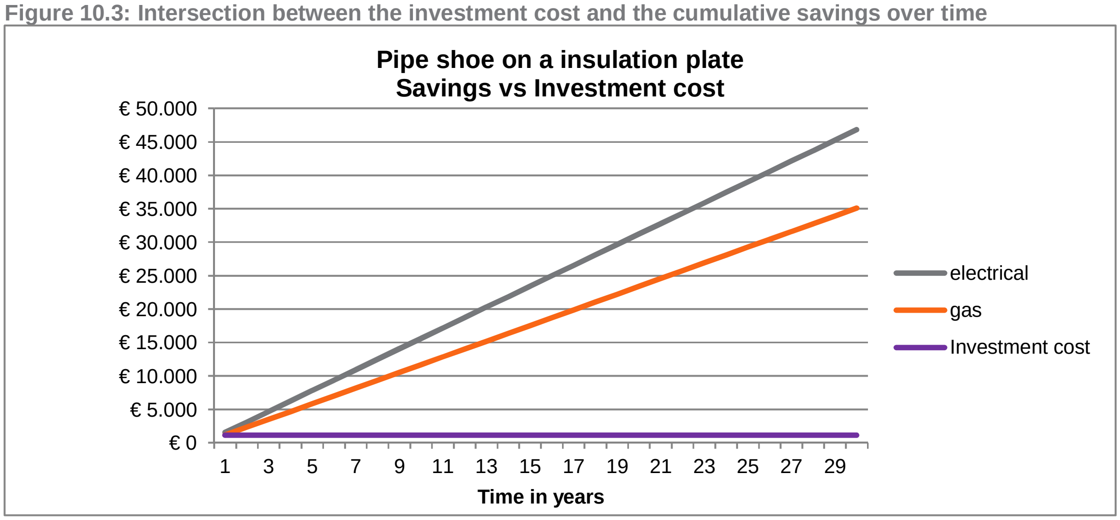



**Figure 10.4: Intersection between the investment cost and the cumulative savings over time**

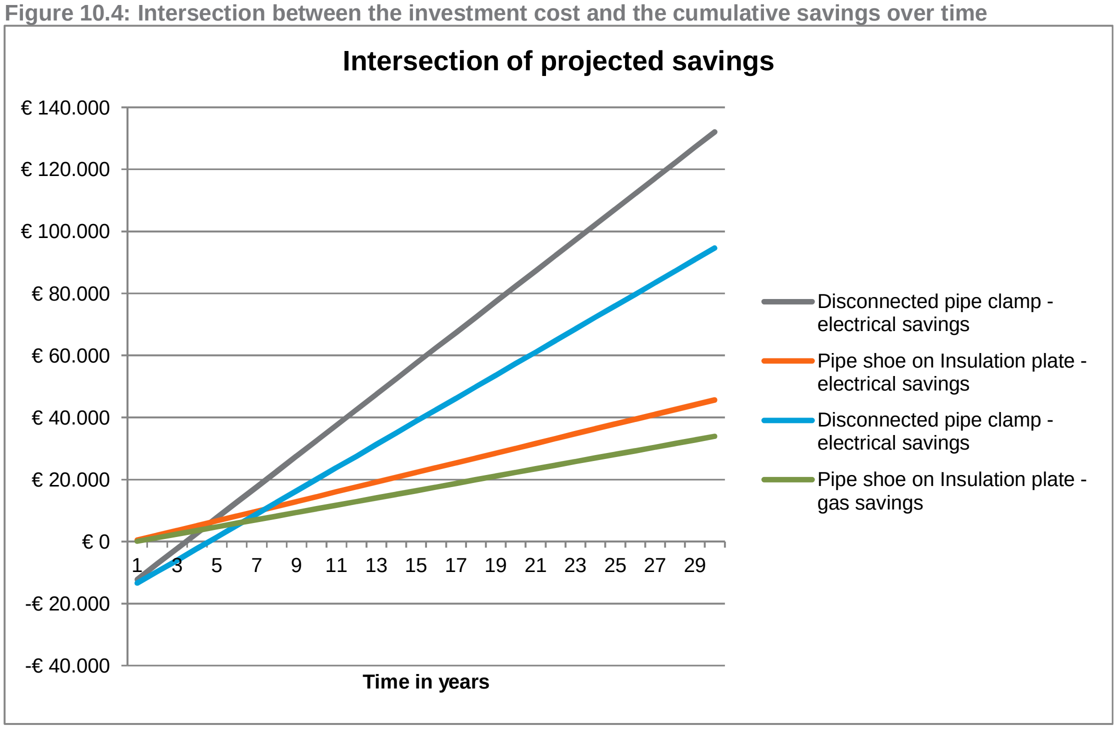



**Figure 10.5: Intersection of cumulative savings per support solution**

### 10.1.3. Conclusion

With the stated boundary condition the following savings and breakeven point can be expected.

| Return of Investment time: Disconnected pipe clamp | |
|---|---|
| Breakeven point electrical heated systems | 3.5 Years |
| Financial savings over 20 years (electrical) | € 99,477 |
| Breakeven point gas heated systems | 4.6 Years |
| Financial savings over 20 years (gas) | € 78,462 |
| Investment for support solution | € 17,167 |
| **Return of Investment time: Shoe support on a plate** | |
| Breakeven point electrical heated systems | 0.7 Years |
| Financial savings over 20 years (electrical) | € 31,217 |
| Breakeven point gas heated systems | 1.0 Years |
| Financial savings over 20 years (gas) | € 24,622.18 |
| Investment for support solution | € 5,582 |

A detailed investigation is advised. The main topics to address are:

- Can an insulation solution be realized in the existing situation?
    - Is there enough space in the existing structures?
    - Is there enough space for either insulation solution?
- Can the existing routing be re-used?
    - Are changes required due to new regulations and/or operational requests?
        - If yes, what changes are applicable in terms of pipe length and number of supports?
- Request a quotation from an insulation/support vendor
- Re-evaluate with the data from the quotation

## 10.2. Example scenario 2: 6[Inch] pipe, crude water mixture at 135[ºC]

Scenario description: A crude oil transportation line will be installed for a new plant. The fluid consists of water and crude oil in a 1:1 ratio. To maintain a low viscosity the fluid temperate in is set at 135 [ºC]

### 10.2.1. Input:

The following scenario specific data needs to be entered into the work file:

- Operating temperature = 135[ºC]
- Specific heat = 3305 [J/kgK]
- Average flow speed = 0.5[m/s]
- Pipe size = 6[Inch]
- Schedule = Standard
- Pipe Insulation thickness = 60[mm]
- Expected life time = 30 [Years]
- Length of pipe = 300 [m]
- Number of shoes 32 [Pce]

### 10.2.2. Output

Based on the input data the following results are returned by the calculations.

**Standard pipe shoe support**

| **Power Balance** | |
|---|---|
| Mean Power Loss per Shoe | 122,52[W] |
| Total Power Loss Through Shoes | 3920,56[W] |
| **Energy balance per 30 year(s)** | |
| Mean Energy Loss per Shoe | 32,20[MWh] |
| Total Energy Loss Through Shoes | 1030,32[MWh] |
| **Costs and outputs related to pipe Shoes per 30 year(s)** | |
| Energy Price Electricity | 57,00 [€/MWh] |
| Consumed Cost Electricity | 58728,45 [€] |
| Energy Price Gas | 11,86 [€/GJ] |
| Consumed Cost Gas [€] | 46321,61 [€] |
| **CO2 output related to pipe Shoes per 30 year(s)** | |
| Expelled CO2 (electricy based) | 19337*10e3[kg] |
| Expelled CO2 (gas based) | 20355*10e3[kg] |

**Disconnected pipe clamp (shoe support)**

| Power Balance | |
|---|---|
| Mean Power Loss per Shoe | 7,41[W] |
| Total Power Loss Through Shoes | 237,08[W] |
| **Energy balance per 30 year(s)** | |
| Mean Energy Loss per Shoe | 1,95[MWh] |
| Total Energy Loss Through Shoes | 62,30[MWh] |
| **Costs and outputs related to pipe Shoes per 30 year(s)** | |
| Energy Price Electricity | 57,00 [€/MWh] |
| Consumed Cost Electricity | 3551,34 [€] |
| Energy Price Gas | 11,86 [€/GJ] |
| Consumed Cost Gas [€] | 2801,09 [€] |
| **CO2 output related to pipe Shoes per 30 year(s)** | |
| Expelled CO2 (electricy based) | 1169*10e3[kg] |
| Expelled CO2 (gas based) | 1231*10e3[kg] |

**Shoe support on insulation plate**

| Power Balance | |
|---|---|
| Mean Power Loss per Shoe | 72,00[W] |
| Total Power Loss Through Shoes | 2303,89[W] |
| **Energy balance per 30 year(s)** | |
| Mean Energy Loss per Shoe | 18,92[MWh] |
| Total Energy Loss Through Shoes | 605,46[MWh] |
| **Costs and outputs related to pipe Shoes per 30 year(s)** | |
| Energy Price Electricity | 57,00 [€/MWh] |
| Consumed Cost Electricity | 34511,30 [€] |
| Energy Price Gas | 11,86 [€/GJ] |
| Consumed Cost Gas [€] | 27220,52 [€] |
| **CO2 output related to pipe Shoes per 30 year(s)** | |
| Expelled CO2 (electricy based) | 11363*10e3[kg] |
| Expelled CO2 (gas based) | 11962*10e3[kg] |

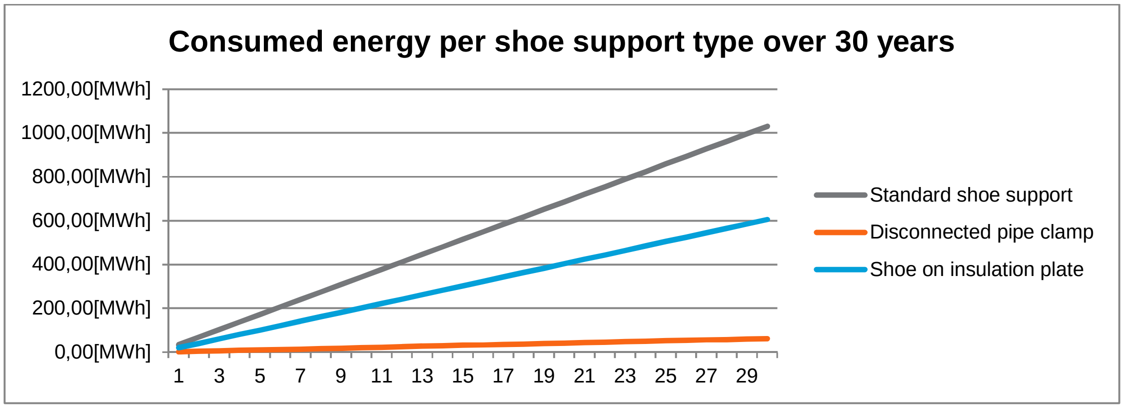



**Figure 10.6: Cumulative heat transfer**

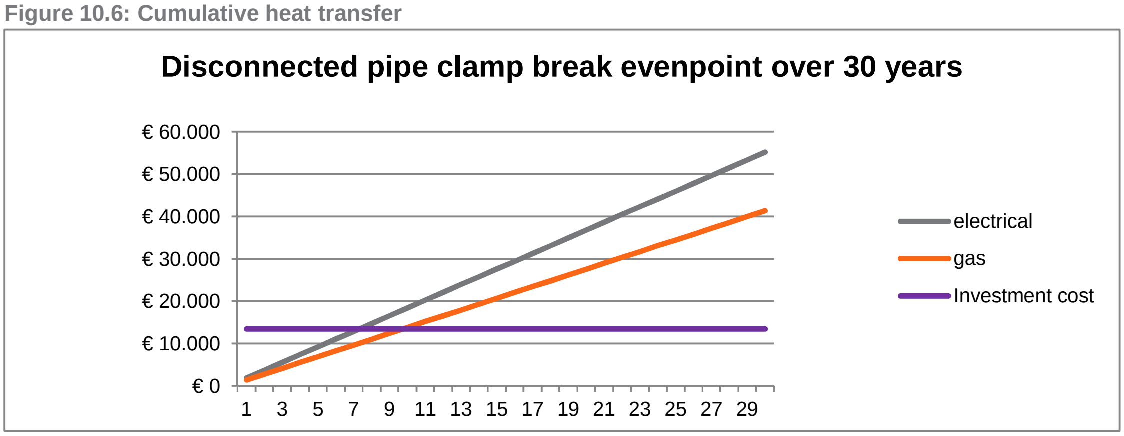



**Figure 10.7: Cumulative cost over time**

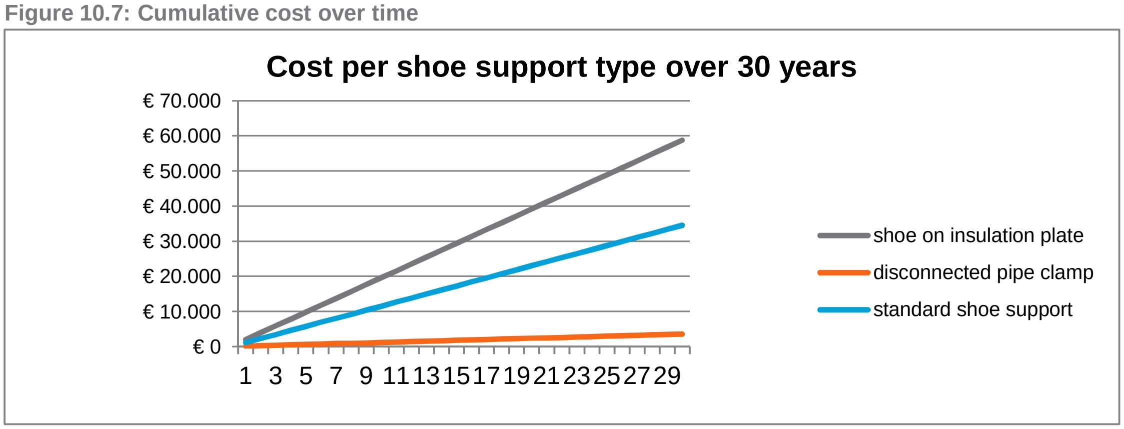



**Figure 10.8: Cumulative cost over time**

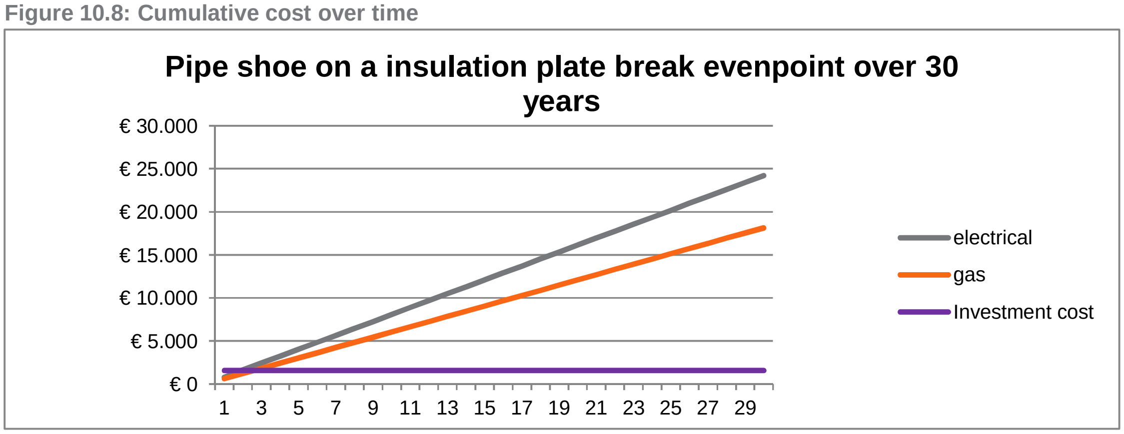



**Figure 10.9:Intersection of cumulative savings per support solution**

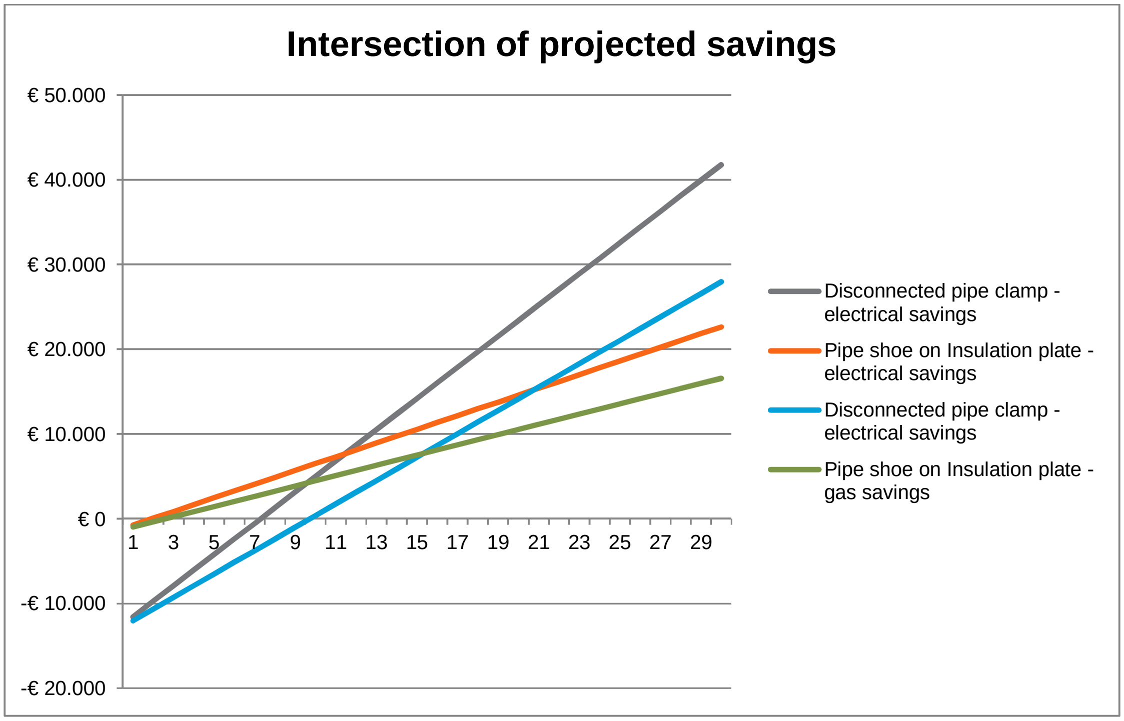



**Figure 10.10: Intersection of cumulative savings per support solution**

### 10.2.3. Conclusion

With the stated boundary condition the following savings and breakeven point can be expected.

| **Return of Investment time: Disconnected pipe clamp** | |
|---|---|
| Breakeven point electrical heated systems | 7.3 Years |
| Financial savings over 30 years (electrical) | € 55.177 |
| Breakeven point gas heated systems | 9.7 Years |
| Financial savings over 30 years (gas) | € 43.520 |
| Investment for support solution | € 17,167 |
| **Return of Investment time: Shoe support on a plate** | |
| Breakeven point electrical heated systems | 1.9 Years |
| Financial savings over 30 years (electrical) | € 24.217 |
| Breakeven point gas heated systems | 2.6 Years |
| Financial savings over 30 years (gas) | € 19.101 |
| Investment for support solution | € 5,582 |

If energy conservation is not required from a process perspective no further investigation is needed. The possible savings are limited relative to the investment and the application of insulated pipe shoes is not expected.

# 11. Recommendations

Based on the result of this assignment a range of piping system can be quickly assessed. However there are some topics to be addressed before the work file generated can be used for on project for our clients.

## 11.1. Investigations

The following investigations are recommended to further increase the applicable range for the calculation file and to improve the quality of the result further.

- Investigate the effect of different pipe insulation materials.
- Investigate the effect of different insulation materials used on pipe shoe supports.
- Investigate the effect of insulation thicknesses above 70[mm]. The increased insulation typically requires a shoe with a higher base. Therefore the geometry changes and the applied equations are no longer applicable.
- Investigate if hanger supports should be included in the work file.
- Investigate the effect of eliminating the (forced) convection on the solution where a pipe shoe support is placed on an insulation plate.
- Investigate the effects of removing material from the pipe shoe on the heat transfer and mechanical properties.

## 11.2. Integration into projects

Before including the work file to the scope of work for projects the following steps are recommended:

- Run pilot analysis of pipe systems in current projects.
    - Analyze the output to determine limitations or problems within the work file.
    - Determine the applicability of the work file.
- If the work file is to be used, a marketing and sales strategy should be formulated.
- Identify piping systems with critical process conditions. Better control over the process conditions could be valuable.
- Identify systems that are heated by dedicated heat sources (e.g. furnaces, steam boilers).

# 12. Conclusion

## 12.1. Results

After analyzing the results from the FEM calculations, doing field measurements and theoretical calculations, the results have been collected an applied in the work file. The work file calculates the costs and savings per support solution. Based on this data the following conclusions can be formulated.

Table 12.1: Answers to the main research questions

| Overview of main research questions | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Pipe size | Maximum heat flow per standard shoe support | Maximum Energy loss through standard shoes per year | Maximum financial loss Per standard shoe | Estimated cost per standard pipe shoe | Estimated cost for solution 1: Disconnected clamp | Relative cost for solution 1: Disconnected clamp | relative savings solution 1: Disconnected clamp | Estimated cost for solution 2: Pipe shoe on insulation plate | Relative cost for solution 2: Pipe shoe on insulation plate | Relative savings solution 2: Shoe on insulation plate |
| 4[Inch] | 254[W] | 67[MWh] | € 3,819 | € 141 | € 407 | 289% | 87% | € 189 | 135% | 28% |
| 6[Inch] | 521[W] | 137[MWh] | € 7,809 | € 200 | € 619 | 309% | 88% | € 249 | 124% | 8% |
| 8[Inch] | 562[W] | 147[MWh] | € 8,379 | € 220 | € 741 | 337% | 80% | € 265 | 120% | 41% |
| 10[Inch] | 570[W] | 149[MWh] | € 8,493 | € 263 | € 870 | 330% | 90% | € 308 | 117% | 19% |
| 12[Inch] | 594[W] | 156[MWh] | € 8,892 | € 319 | € 1,005 | 315% | 89% | € 364 | 114% | 26% |
| 14[Inch] | 619[W] | 162[MWh] | € 9,234 | € 346 | € 1,083 | 313% | 94% | € 387 | 112% | 17% |
| 16[Inch] | 738[W] | 193[MWh] | € 11,001 | € 496 | € 1,219 | 246% | 96% | € 542 | 109% | 9% |
| 20[Inch] | 876[W] | 230[MWh] | € 13,110 | € 596 | € 1,472 | 247% | 93% | € 642 | 108% | 25% |

## 12.2. Investment decisions

Investing in pipe shoe solution can be profitable as shown in chapter10.1. The financial analysis must be made per project and per piping system. The excel work file has been setup to facilitate practically all fluids and gasses. The output can help make an investment decision.

### 12.1. A usefull tool has been created to analyze the heat loss through pipe shoe supports

The goal to create a standard calculation file in excel has been achieved. Any system from 4[Inch] up to and including 20[Inch] can be analyzed. The accuracy of the predictions are related to the phase of the project (e.g. select, basic design and detailed phase). The costs, savings and CO2 output are given as output in tables and graphs. Therefore the requirements have been met. A basis to continue investigating and improving upon has been established.

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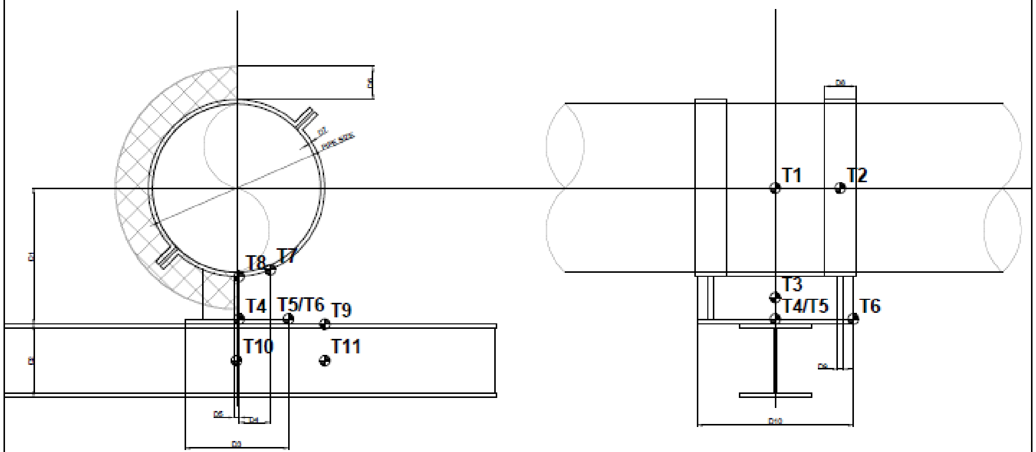
## Appendix I: Field measurement template




| | |
|---|---|
| PIPE SIZE | |
| INSU. THICK. | |
| OPP. TEMP | |
| Tamb | |
| Vwind | |

| | |
|---|---|
| T1 | |
| T2 | |
| T3 | |
| T4 | |
| T5 | |
| T6 | |
| T7 | |
| T8 | |
| T9 | |
| T10 | |

| | |
|---|---|
| D1 | |
| D2 | |
| D3 | |
| D4 | |
| D5 | |
| D6 | |
| D7 | |
| D8 | |
| D9 | |
| D10 | |

ADDITIONAL NOTES/REMARKS /CONDITIONS

## Appendix II: Excel work file input sheet

| Boundary Conditions | |
|---|---|
| Operating Temperature at start of pipe | 50[C] |
| Fluid specific heat | 4100[J/kgK] |
| Flow speed | 50,0[m/s] |
| Average Temperature | 50[C] |
| Average ambient Temperature | 10[C] |
| Pipe Size | 20[Inch] |
| Pipe Size [DN] | 508,0[mm] |
| Pipe Schedule | STD |
| Pipe Schedule | 48,9[mm] |
| Insulation Thickness | 60[mm] |
| Pipe line Length | 100[m] |
| Number of Pipe Shoes | 10[PCS] |
| Nember of years to review | 1[Yrs] |

**Enter Data in the blue field**
**Select data from the green field**
**[1] Enter temperature in [C] , 0 to 500**
**[2] enter the specific heat of the medium**
**[3] the flow speed**
**[4] Enter pipe size**
**[5] Select pipe schedule**
**[6] select support solution**
**[7] enter insulation thickness per 50/60/70[mm]**
**[8] Enter length of pipe system**
**[8] Enter number op pipe shoes on pipe system**
**[9] Enter years to review**

**Standard pipe shoe support**

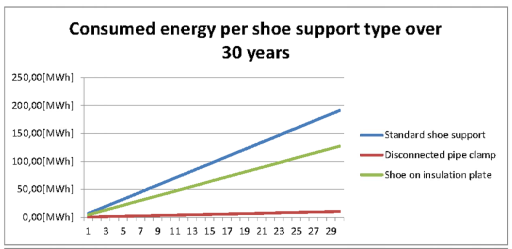
| Power Balance | |
|---|---|
| Mean Power Loss per Shoe | 72,78[W] |
| Total Power Loss Through Shoes | 727,75[W] |
| **Energy balance per 1 year(s)** | |
| Mean Energy Loss per Shoe | 0,64[MWh] |
| Total Energy Loss Through Shoes | 6,38[MWh] |
| **Costs and outputs related to pipe Shoes per 1 year(s)** | |
| Energy Price Electricity | 57,00 [€/MWh] |
| Consumed Cost Electricity | 363,38 [€] |
| Energy Price Gas | 11,86 [€/GJ] |
| Consumed Cost Gas [€] | 286,62 [€] |
| **CO2 output related to pipe Shoes per 1 year(s)** | |
| Expelled CO2 (electricy based) | 4*10e3[kg] |
| Expelled CO2 (gas based) | 4*10e3[kg] |

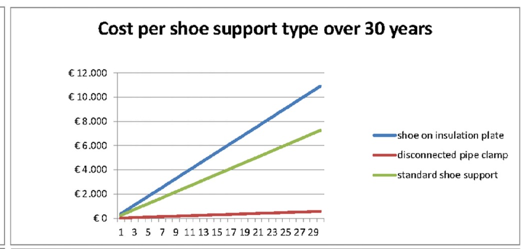
**Disconnected pipe clamp (shoe support)**

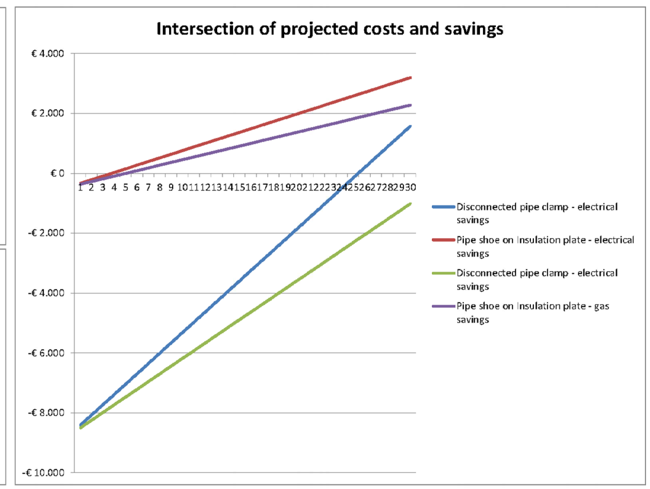
| Power Balance | |
|---|---|
| Mean Power Loss per Shoe | 3,79[W] |
| Total Power Loss Through Shoes | 37,89[W] |
| **Energy balance per 1 year(s)** | |
| Mean Energy Loss per Shoe | 0,03[MWh] |
| Total Energy Loss Through Shoes | 0,33[MWh] |
| **Costs and outputs related to pipe Shoes per 1 year(s)** | |
| Energy Price Electricity | 57,00 [€/MWh] |
| Consumed Cost Electricity | 18,92 [€] |
| Energy Price Gas | 11,86 [€/GJ] |
| Consumed Cost Gas [€] | 14,92 [€] |
| **CO2 output related to pipe Shoes per 1 year(s)** | |
| Expelled CO2 (electricy based) | 0*10e3[kg] |
| Expelled CO2 (gas based) | 0*10e3[kg] |

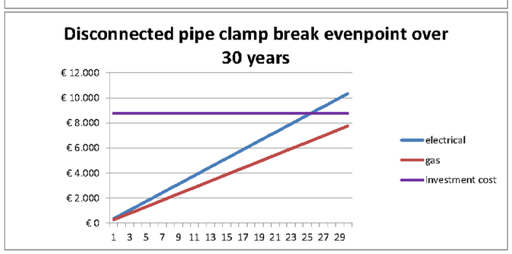
**Shoe support on insulation plate**

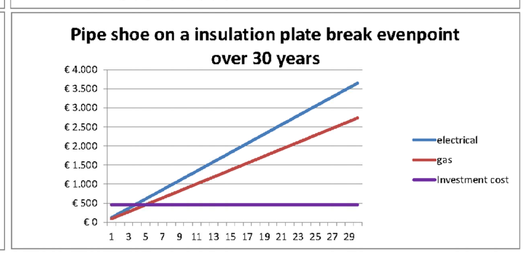
| Power Balance | |
|---|---|
| Mean Power Loss per Shoe | 48,41[W] |
| Total Power Loss Through Shoes | 484,11[W] |
| **Energy balance per 1 year(s)** | |
| Mean Energy Loss per Shoe | 0,42[MWh] |
| Total Energy Loss Through Shoes | 4,24[MWh] |
| **Costs and outputs related to pipe Shoes per 1 year(s)** | |
| Energy Price Electricity | 57,00 [€/MWh] |
| Consumed Cost Electricity | 241,73 [€] |
| Energy Price Gas | 11,86 [€/GJ] |
| Consumed Cost Gas [€] | 190,66 [€] |
| **CO2 output related to pipe Shoes per 1 year(s)** | |
| Expelled CO2 (electricy based) | 3*10e3[kg] |
| Expelled CO2 (gas based) | 3*10e3[kg] |




| Return of Investment time: Disconnected pipe clamp | |
|---|---|
| Break even point electrical heated systems | 25,4[Yrs] |
| Financial savings over 30 years (eletrical) | € 344,46 |
| Break even point gas heated systems | 34,0[Yrs] |
| Financial savings over 30 years (gas) | € 271,69 |

| Return of Investment time: Shoe support on a plate | |
|---|---|
| Break even point electrical heated systems | 3,8[Yrs] |
| Financial savings over 30 years (eletrical) | € 121,66 |
| Break even point gas heated systems | 5,0[Yrs] |
| Financial savings over 30 years (gas) | € 95,96 |

## Appendix III: Calculation sheet, investment cost for pipe shoe solutions

Investment Costs for pipe shoe solutions

Number of supports reviewed: 10

| | | | 4[Inch] | 6[Inch] | 8[Inch] | 10[Inch] | 12[Inch] | 14[Inch] | 16[Inch] | 20[Inch] |
|---|---|---|---|---|---|---|---|---|---|---|
| Standard pipe shoe support | **weight per shoe per pipe size h=100** | | 8[kg] | 13[kg] | 14[kg] | 18[kg] | 22[kg] | 24[kg] | 36[kg] | 44[kg] |
| | **Price @ Steel cost** | 12[€/kg] | € 1.008 | € 1.560 | € 1.716 | € 2.112 | € 2.628 | € 2.856 | € 4.320 | € 5.280 |
| | **Standard shoe support installation time** | | 1,00[h] | 1,10[h] | 1,20[h] | 1,30[h] | 1,40[h] | 1,50[h] | 1,60[h] | 1,70[h] |
| | **Standard shoe support installating cost** | 40[€/h] | € 400 | € 440 | € 480 | € 520 | € 560 | € 600 | € 640 | € 680 |
| | **Standard shoe support** | Total | **€ 1.408** | **€ 2.000** | **€ 2.196** | **€ 2.632** | **€ 3.188** | **€ 3.456** | **€ 4.960** | **€ 5.960** |
| Disconnected pipe clamp | **weight of shoe for disconnected clamp** | | 23[kg] | 37[kg] | 45[kg] | 53[kg] | 62[kg] | 66[kg] | 75[kg] | 91[kg] |
| | **Price @ Steel cost** | 12[€/kg] | € 2.708 | € 4.496 | € 5.397 | € 6.355 | € 7.397 | € 7.959 | € 9.001 | € 10.944 |
| | **Surface monolux m2 per size** | | 0,26[M2] | 0,36[M2] | 0,46[M2] | 0,56[M2] | 0,66[M2] | 0,72[M2] | 0,81[M2] | 1,00[M2] |
| | **monolux d=50.8mm round cost** | 289[€/m2] | € 758 | € 1.052 | € 1.328 | € 1.622 | € 1.898 | € 2.071 | € 2.347 | € 2.900 |
| | **disconnected support installation time** | | 1,50[h] | 1,60[h] | 1,70[h] | 1,80[h] | 1,90[h] | 2,00[h] | 2,10[h] | 2,20[h] |
| | **Disconnected pipe clamp installation cost** | 40[€/h] | € 600,00 | € 640,00 | € 680,00 | € 720,00 | € 760,00 | € 800,00 | € 840,00 | € 880,00 |
| | **Disconnected pipe clamp** | Total | **€ 4.066,18** | **€ 6.187,88** | **€ 7.405,14** | **€ 8.696,55** | **€ 10.054,93** | **€ 10.829,56** | **€ 12.187,94** | **€ 14.723,58** |
| | **Additional investment cost compared standard pipe shoe support** | | **€ 2.658,18** | **€ 4.187,88** | **€ 5.209,14** | **€ 6.064,55** | **€ 6.866,93** | **€ 7.373,56** | **€ 7.227,94** | **€ 8.763,58** |
| Shoe on insulation plate | **weight per shoe per pipe size h=100** | | 8[kg] | 13[kg] | 14[kg] | 18[kg] | 22[kg] | 24[kg] | 36[kg] | 44[kg] |
| | **Price @ Steel cost** | 12[€/kg] | € 1.008 | € 1.560 | € 1.716 | € 2.112 | € 2.628 | € 2.856 | € 4.320 | € 5.280 |
| | **monolux m2 per size** | | 0,03[M2] | 0,05[M2] | 0,05[M2] | 0,05[M2] | 0,06[M2] | 0,06[M2] | 0,08[M2] | 0,09[M2] |
| | **monolux d=50.8mm cost** | 289[€/m2] | € 87 | € 130 | € 130 | € 130 | € 173 | € 173 | € 216 | € 260 |
| | **Shoe on insulation plate installation time** | | 2,00[h] | 2,00[h] | 2,00[h] | 2,10[h] | 2,10[h] | 2,10[h] | 2,20[h] | 2,20[h] |
| | **Shoe on insulation plate installation cost** | 40[€/h] | € 800 | € 800 | € 800 | € 840 | € 840 | € 840 | € 880 | € 880 |
| | **Shoe on insulation plate** | Total | **€ 1.895** | **€ 2.490** | **€ 2.646** | **€ 3.082** | **€ 3.641** | **€ 3.869** | **€ 5.416** | **€ 6.420** |
| | **Relative investment against standard pipe shoe support** | | **€ 486,59** | **€ 1.081,89** | **€ 1.237,89** | **€ 1.673,89** | **€ 2.233,18** | **€ 2.461,18** | **€ 4.008,48** | **€ 5.011,78** |