PIPELINE TEMPERATURE DISTRIBUTION END-USER MANUAL-SAMPLE

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1 INTRODUCTION

When transporting a fluid product (water, oil, gas, …), it is sometimes necessary to maintain the transported fluid above or below a set temperature at the discharge end. This temperature maintenance is crucial for some processes in order to assure quality, to prevent clogging of the pipeline or to prevent formation of certain chemicals that can be harmful to the pipeline and/or to the downstream processes when conveyed fluid being discharged.

As a result, pipeline designers are always required to check for the temperature distribution along the pipeline to ensure its adequacy to the thermal energy loss/gain that is set for the processes this pipeline is designed for. When inadequate, pipe wall layers and operating conditions are investigated to make it adequate

1.1 Purpose of Document

This document is developed as a manual for the user to detail the temperature distribution along a pipeline. The detailed steps in this document will guide the user to the procedure to follow in generating the temperature profile along the pipeline considering user-defined layers and vertical profiles of ambient temperature and outer flow velocity.

1.2 Focus of Document

This document will focus on the following criteria for the pipeline analysis:

- The pipeline can take different straight profiles from its inlet to its discharging point. This profile is exposed to changes in vertical elevation, environmental temperature and external convection along its route. The external environment is considered time-independent and polynomial curve-fitted based on user-defined vertical profiles of ambient temperature and outer flow velocity.
- The pipe wall layers are not changing in thickness along the pipeline route from its beginning to its end.
- The inner flow is assumed as a single-phase steady flow with a fixed inlet temperature and a fixed flow rate.
- Only forced convection at the innermost and the outermost pipe surfaces is considered. i.e. natural/free convection is not accounted for in this document.
- The heat transfer occurs only across the pipe wall layers with a negligible effect of lateral heat transfer within the internal fluid and along the pipe wall.
- The friction due to the innermost surface roughness is the only roughness-related parameter considered to affect the heat transfer process whenever referenced. That is, other roughness parameters, such as equivalent sand grain roughness, are ignored.
- Only fluids with Prandtl Number >1 are considered.

1.3 Units and Dimensions

All units and dimensions are applicable in this document. All variables and parameters must be defined on the basis of the same units system. This document does not account for unit conversion.

2 SYMBOLS AND ABBREVIATIONS

Below is a list of symbols and abbreviations that are used in this document. Other specific symbols and abbreviations, if any, will be defined in place.

ang	: Pipeline inclination angle with vertical
$Cp_{fluid-i}$	: Specific heat of fluid-i
h_{in}	: Convective heat transfer coefficient at the innermost pipe surface
$h_{out-avg}$	: Averaged convective heat transfer coefficient at the outermost pipe surface.
ID_{in}	: The innermost pipe diameter
$k_{layer-i}$	: Thermal conductivity of layer-i
$kf_{fluid-i}$	: Thermal conductivity of fluid-i
L	: Pipeline overall length
m	: Total number of elements the pipeline is divided in
$\dot{m}_{in}$	: Mass flow rate of inner flow
$Pr_{fluid-i}$	: Prandtl Number of fluid-i
$\dot{Q}_{in}$	: Volume flow rate of inner flow
R_{pipe-i}	: Overall thermal resistance of pipe at position/node "i" of the pipeline
Re_{in}	: Reynold's Number of inner flow
Re_{out-i}	: Reynold's Number of outer flow at position/node "i" of the pipeline
SI	: International System of Units
T_{amb-i}	: Ambient Temperature at position/node "i" of the pipeline
T_{b_in}	: Bulk Temperature of the inner flow
T_{deg}	: Polynomial degree curve-fitting ambient temperature profile with vertical
T_i	: Temperature at position/node "i"
T_{in}	: Temperature at pipeline inlet
$t_{layer-i}$	: Thickness of layer-i
U_{coef}	: Averaged overall heat transfer coefficient
V_{deg}	: Polynomial degree curve-fitting outer flow velocity profile with vertical
X	: Vector of vertical coordinate over which profile is defined
Y	: Vector of defined profile values per coordinates in vector X
ε	: Innermost pipe surface roughness
$\mu_{fluid-i}$	: Dynamic viscosity of fluid-i
$\rho_{fluid-i}$	: Density of fluid-i
ΔL	: Pipeline elemental length

3 ANALYSIS PROCEDURE

3.1 General

The analysis procedure for the temperature distribution along the pipeline is based on calculating the amount of transferred heat energy across the pipe wall as the internal fluid flows from inlet towards the discharge end.

3.2 Concept

The concept of analysis is to divide the length of the pipeline into elements across each thermal energy balance is applied starting from the element adjacent to the inlet towards the element adjacent to the discharge end. This elemental energy balance will result in calculating the element discharge temperature after accounting for the effect of the heat energy flow across the pipe wall on the element inlet energy. This element discharge temperature will be used as an inlet temperature for the next element and so on until the last element is considered. The transferred heat energy across the pipe wall is governed by the overall heat transfer coefficient of the pipe wall which depends on the wall layers and the conditions of the inner and the outer flows.

A simple representation of the energy balance within a pipeline element is schematically shown in **Error! Reference source not found.**.

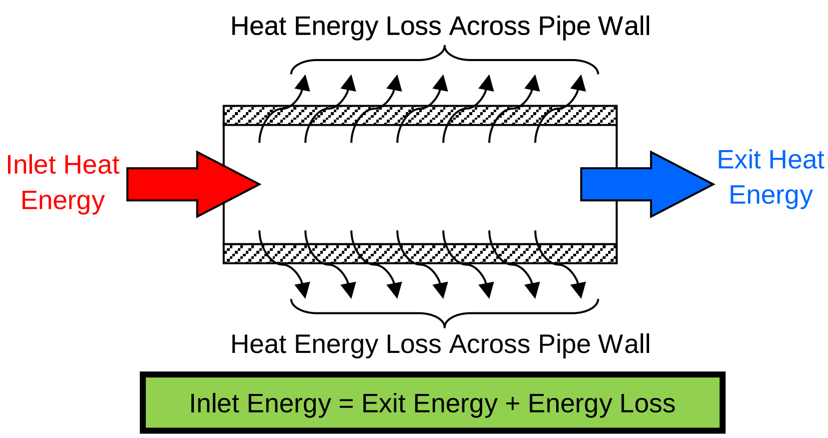

Figure 3-1: A schematic of heat energy balance within a pipeline element

3.3 Calculations

The computer routine associated with this manual is designed to perform the calculations of the pipe thermal resistances, according to the user-defined sequence of pipe wall layers and profiles of ambient temperature and outer flow velocity. Further, it calculates nodal overall heat transfer coefficients along the pipeline with their associated standard deviation and their mean U_{coef}.

Reference to [1], the performed calculations account for the convective heat transfer coefficients of the internal and the external fluids through the following correlations:

1- Mills correlation for laminar inner flow.
2- Gnielinski's correlation for turbulent inner flow as long as an approximate range of $3000 \leq Re_{in} \leq 5x10^{6}$ is satisfied.

3- Churchill-Bernstein correlation for outer flow as long as ($Pr_{\text{fluid-2}} * Re_{\text{out-i}}$) ≥ 0.2.

All required parameters for the above-mentioned correlations are automatically accounted for such as the friction factor at the innermost surface, the Prandtl numbers of the internal and the external fluids and the Reynolds numbers of the inner and the outer flows.

4- The energy balance throughout each element results into the nodal temperature formula that is detailed by eqn. (1).

$$T_{\text{i}} = T_{\text{i-1}} - \Delta L * \left(T_{\text{i-1}} - T_{\text{amb-(i-1)}}\right) / \left(R_{\text{pipe-(i-1)}} * Cp_{\text{fluid-1}} * \dot{Q}_{\text{in}} * \rho_{\text{fluid-1}}\right),\ \text{m} \geq \text{i} \geq 1,\ T_0 = T_{\text{in}} \quad (1)$$

It should be noted that the elemental temperature difference between the inner flow and the outer flow is assuming that the inner flow bulk temperature of the pipe is the same as the elemental inlet temperature and properties of both internal and external fluids are evaluated at $T_{\text{b\_in}}$ and $T_{\text{amb-i}}$, respectively. This assumption is acceptable because $T_{\text{b\_in}} \approx T_{\text{in}}$ as the element size becomes smaller. In addition, the properties of the considered fluids are slowly changing over a relatively large temperature range and the applications of such fluids are generally handled below superheated temperatures which justify the evaluation of these properties at $T_{\text{b\_in}}$ and $T_{\text{amb-i}}$.

Figure 3-2 shows a schematic example of the temperature profile as heat energy transfers between the internal fluid and the external fluid considering the effect of layers conductivity and the convection at both the innermost and the outermost pipe surfaces.

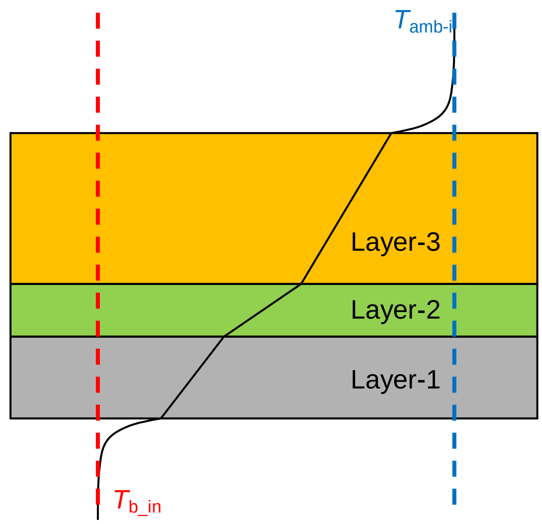

Figure 3-2: A schematic of temperature profile from internal to external fluids across pipe wall layers

4 ANALYSIS ROUTINE

4.1 General

The analysis procedure is translated into a computer routine to generate the temperature distribution along the pipeline as well as the overall heat transfer coefficient of the pipe.

4.2 User Input File

For the computer routine to perform the analysis correctly,

1) The user needs to input the required information as described in the template of Table 4-1.
2) The user needs to maintain the sequence of line numbers as specified without being altered.
3) Maintenance of units' consistency for all input parameters is important.

Upon generating the input file, considering the above-mentioned conditions, the user is to save this file as "16010001301010000101.txt" in the same folder of the executable file.

Table 4-1: Template for user-input parameters

1	ID_{in}					
2	ε					
3	L					
4	ang					
5	ΔL					
6	T_{deg}					
7	V_{deg}					
0[b]	----------[a]					
8	layer-1[d][e]	$k_{(layer-1)}$	$t_{(layer-1)}$			
9	layer-2[d][e]	$k_{(layer-2)}$	$t_{(layer-2)}$			
:	:	:	:			
n+7[c]	layer-n[d][e]	$k_{(layer-n)}$	$t_{(layer-n)}$			
0[b]	----------[a][a]					
n+8	fluid-1[f]	$\rho_{fluid-1}$	$\mu_{fluid-1}$	$kf_{fluid-1}$	$Cp_{fluid-1}$	$\dot{Q}_{in}$
n+9	fluid-2[f]	$\rho_{fluid-2}$	$\mu_{fluid-2}$	$kf_{fluid-2}$	$Cp_{fluid-2}$	
0[b]	----------[a]					
n+10	T_{in}					
0[b]	----------[a]					
n+11	X(1)	Y(1)				
n+12	X(2)	Y(2)				
:	:	:				
nT+n+10[h]	X(nT)[g]	Y(nT)[g]				
0[b]	----------[a]					

nT+n+11	X(1)	Y(1)				
nT+n+12	X(2)	Y(2)				
:	:	:				
nV+nT+n+10[i]	X(nV)[g]	Y(nV)[g]				
0[b]	----------[a]					

(a) These dashes are field separators and need to be input as is (10 dashes).
(b) This "0" is a controlling line index for the routine to read input parameters properly.
(c) The value of "n" depends on the number of pipe wall layers. The more layers are added, the more lines are added from line "8" till the next controlling line "0".
(d) Name of the layer (optional to user to name it).
(e) Layers must be inserted in sequence starting from the innermost "at line 8" and ending at the outermost "at line n+7". This is important for thermal resistances to be correctly calculated.
(f) Always consider "fluid-1" to be the internal fluid and "fluid-2" to be the external/environmental fluid (optional to user to name the fluid).
(g) X coordinate values must be inserted in sequence starting from the pipeline inlet coordinate in the +ve vertical direction. Similarly Y values must be inserted in the same sequence as in X.
(h) The value of "nT" depends on the number of ambient temperature data inserted by user. The more data are added, the more lines are added from line "n+11" till the next controlling line "0".
(i) The value of "nV" depends on the number of outer flow velocity data inserted by user. The more data are added, the more lines are added from line "nT+n+11" till the next controlling line "0".

4.3 Output File

Upon the execution of the computer routine, the following information are extracted in the output file "16010001311010000101.txt":

1) The pipe averaged overall heat transfer coefficient (U_{coef}).
2) The convective heat transfer coefficient of the innermost surface of the pipeline (h_{in})- obtained through the full version of the computer routine.
3) The averaged convective heat transfer coefficient of outermost surface of the pipeline ($h_{out\text{-}avg}$) obtained through the full version of the computer routine.
4) The standard deviation of the nodal overall heat transfer coefficients.
5) The mass flow rate of the internal fluid ($\dot{m}_{in}$).
6) The temperature distribution profile along the pipeline (T_i, $m \geq i \geq 0$). For long pipelines, the middle third of T vector is blocked and can be obtained through the full version of the computer routine.

4.4 Sample Problem

An actual sample problem is presented herein to familiarize the user with the computer routine and to evaluate its capability in handling similar analysis problems. The problem is to calculate the temperature profile of a 100 meter insulated pipeline that is laid horizontally at 1000 m water depth. The pipe wall consists of (n = 1) layers. Table 4-2 lists the input file information for the sample problem in SI units system.

Table 4-2: Input parameters of the sample problem

1	0.1159					
2	0.00085					
3	100					
4	90					
5	2					
6	3					
7	2					
0	----------					
8	Steel	63.2	0.0127			
0	----------					
9	Oil	855	0.05	0.1366	1842	0.00739
10	Seawater	1025	0.00108	0.609	3993	
0	----------					
11	120					
0	----------					
12	0	11				
13	300	11				
14	800	11				
15	1000	11				
0	----------					
16	0	0.4				
17	300	0.4				
18	800	0.4				
19	1000	0.4				
0	----------					

Upon the execution of the computer routine for the input file, as detailed in Table 4-2, the temperature distribution along the pipeline line results as shown in Figure 4-1.

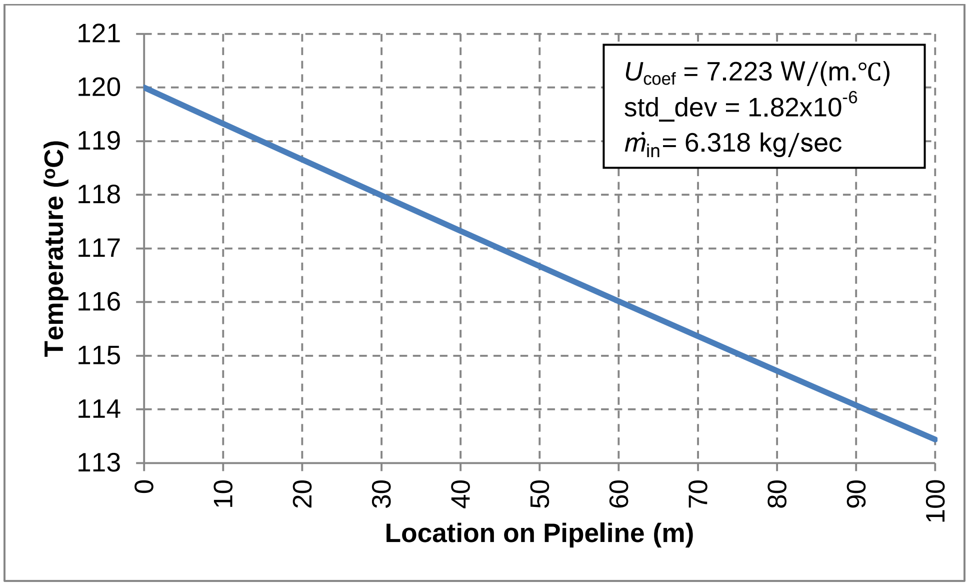

Figure 4-1: Temperature distribution profile along a sample problem pipeline

5 REFERENCES

[1] CNAT Doc. No.: 1401000110001000010A, “Pipeline Temperature Distribution Manual”.