Package 'pipenostics'

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Type Package

Title Diagnostics, Reliability and Predictive Maintenance of Pipeline Systems

Version 0.2.0

Description Functions representing some useful empirical and data-driven models of heat loss, corrosion diagnostics, reliability and predictive maintenance of pipeline systems. The package is an option for technical engineering departments of heat generating and heat transfer companies that use or plan to use regulatory calculations in their activities. Methods are described in Timashev et al. (2016) <doi:10.1007/978-3-319-25307-7>, A.C.Reddy (2017) <doi:10.1016/j.matpr.2017.07.081>, Minenergo (2008) <https://docs.cntd.ru/document/902148459>, Minenergo (2005) <https://docs.cntd.ru/document/1200035568>, Xing LU. (2014) <doi:10.1080/23744731.2016.1258371>.

URL https://omega1x.github.io/pipenostics/

BugReports https://github.com/omega1x/pipenostics/issues

License GPL-3

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Contents

`pipenostics-package` *pipenostics: Diagnostics, Reliability and Predictive Maintenance of Pipeline Systems*

Description

Functions representing some useful empirical and data-driven models of heat loss, corrosion diagnostics, reliability and predictive maintenance of pipeline systems. The package is an option for technical engineering departments of heat generating and heat transfer companies that use or plan to use regulatory calculations in their activities. Methods are described in Timashev et al. (2016) doi:10.1007/9783319253077, A.C.Reddy (2017) doi:10.1016/j.matpr.2017.07.081, Minenergo (2008) https://docs.cntd.ru/document/902148459, Minenergo (2005) https://docs.cntd.ru/document/1200035568, Xing LU. (2014) doi:10.1080/23744731.2016.1258371.

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See Also

Useful links:

- https://omega1x.github.io/pipenostics/
- Report bugs at https://github.com/omega1x/pipenostics/issues

api5l3t *API 5L. Values of SMYS and UTS*

Description

Data represents specified minimum yield strength (SMYS) and ultimate tensile strength (UTS) both achieved when producing line pipes according to API SPECIFICATION 5L.

Usage

```
api5l3t
```

Format

A data frame with 11 rows and 3 variables:

grade designation of standard grade of manufactured pipe. Type: assert_character.

smys SMYS - specified minimum yield strength, [*psi*]. Type: assert_double.

uts UTS - ultimate tensile strength, [*psi*]. Type: assert_double.

Source

https://law.resource.org/pub/us/cfr/ibr/002/api.5l.2004.pdf

b31crvl *ASME B31G. Basic computer program CRVL.BAS*

Description

Imitation of *CVRL.BAS* computer program presented in ASME B31G-1991 *Appendix A* for determining allowable length and allowable operating pressure

Usage

```
b31crvl(maop, d, wth, smys, def = 0.72, depth, l)
```

Arguments

maop	maximum allowable operating pressure - *MAOP*, [*PSI*]. Type: assert_double.
d	nominal outside diameter of pipe, [*inch*]. Type: assert_double.
wth	nominal wall thickness of pipe, [*inch*]. Type: assert_double.
smys	specified minimum yield of stress (*SMYS*) as a characteristics of steel strength, [*PSI*]. Type: assert_double.

def	appropriate (combined) design factor from ASME B31.4, ASME B31.8, or ASME B31.11, []. Type: assert_double.
depth	measured maximum depth of the corroded area, [*inch*]. Type: assert_double.
l	measured maximum longitudinal length of the corroded area, [*inch*]. Type: assert_double.

Details

Columns *maop*, *d*, *wth*, *smys*, *def*, *depth*, *l* in the output *data.frame* come from function's input, other columns are calculated.

For univariate case (when lengths of all input vectors are one) messages that imitate *CRVL.BAS* console output are printed.

Value

Object of *S3*-class *crvl* which is a *data.frame* with the next numeric columns:

maop maximum allowable operating pressure - *MAOP*, [*PSI*]. Type: assert_double.

d nominal outside diameter of pipe, [*inch*]. Type: assert_double.

wth nominal wall thickness of pipe, [*inch*]. Type: assert_double.

smys specified minimum yield of stress (*SMYS*) as a characteristics of steel strength, [*PSI*]. Type: assert_double.

def appropriate (combined) design factor from ASME B31.4, ASME B31.8, or ASME B31.11, []. Type: assert_double.

depth measured maximum depth of the corroded area, [*inch*]. Type: assert_double.

l measured maximum longitudial length of corroded area, [*inch*]. Type: assert_double.

status Operational status of pipe: *1* - excellent, *2* - monitoring is recommended, *3* - alert! replace the pipe immediately! Type: assert_numeric.

design_pressure design pressure of pipe, [*PSI*]. Type: assert_double.

safe_pressure safe maximum pressure for the corroded area, [*PSI*]. Type: assert_double.

pressure_exceeding whether operator's action is required to reduce *MOAP* lower than the maximum safe pressure of the corroded area. Type: assert_logical.

allowed_corrosion_depth allowable depth of the corroded area, [*inch*]. Type: assert_double.

A intermediate factor related to the geometry of the corroded area, []. Type: assert_double.

allowed_corrosion_length allowable length of the corroded area, [*inch*]. Type: assert_double.

AP another intermediate factor related to the geometry of the corroded area, []. Type: assert_double.

References

ASME B31 G-1991. Manual for determining the remaining strength of corroded pipelines. A supplement to *ASME B31G* code for pressure piping.

See Also

Other ASME B31G functions: b31gacd(), b31gacl(), b31gafr(), b31gdep(), b31gmodpf(), b31gops(), b31gpf(), b31gsap()

Examples

```
library(pipenostics)

## Further examples are inspired by those used in Appendix A of
## ASME B31G-1991 to verify correct entry of CRVL.BAS source code

## Example 1
b31crvl(maop = 910, d = 30, wth = .438, smys = 52000, def  = .72, depth = .1, l = 7.5)
#
# -- Calculated data --
# Intermediate factor (A) = 1.847
# Design pressure = 1093 PSI; Safe pressure = 1093 PSI
# Pipe may be operated safely at MAOP, 910 PSI
# With corrosion length 7.500 inch, maximum allowed corrosion depth is 0.2490 inch; A = 1.847
# With corrosion depth 0.100 inch, maximum allowed corrosion length is Inf inch; A = 5.000


## Example 2
b31crvl(maop = 400, d = 20, wth = .25, smys = 35000, def  = 0.5, depth = 0.18, l = 10)
#
# -- Calculated data --
# Intermediate factor (A) = 3.993
# Design pressure = 438 PSI; Safe pressure = 284 PSI
# Reduce operating pressure so it will not exceed 284 PSI, and so operate legally and safely
# With corrosion length 10.000 inch, maximum allowed corrosion depth is 0.0790 inch; A = 3.993
# With corrosion depth 0.180 inch, maximum allowed corrosion length is 2.0180 inch; A = 0.806


## Example 3
b31crvl(maop = 910, d = 24, wth = .432, smys = 52000, def  = .72, depth = 0.13, l = 30)
#
# -- Calculated data --
# Intermediate factor (A) = 8.320
# Design pressure = 1348 PSI; Safe pressure = 1037 PSI
# Pipe may be operated safely at MAOP, 910 PSI
# With corrosion length 30.000 inch, maximum allowed corrosion depth is 0.1670 inch; A = 8.320
# With corrosion depth 0.130 inch, maximum allowed corrosion length is Inf inch; A = 5.000


## Example 4
b31crvl(maop = 910, d = 24, wth = .432, smys = 52000, def  = .72, depth = .3, l = 30)
#
# -- Calculated data --
# Intermediate factor (A) = 8.320
# Design pressure = 1348 PSI; Safe pressure = 453 PSI
# Reduce operating pressure so it will not exceed 453 PSI, and so operate legally and safely
# With corrosion length 30.000 inch, maximum allowed corrosion depth is 0.1670 inch; A = 8.320
# With corrosion depth 0.300 inch, maximum allowed corrosion length is 12.8670 inch; A = 3.568


## Example 5
b31crvl(maop = 731, d = 24, wth = .281, smys = 52000, def  = 0.72, depth = 0.08, l = 15)
```

```
#
# -- Calculated data --
# Intermediate factor (A) = 5.158
# Design pressure = 877 PSI; Safe pressure = 690 PSI
# Reduce operating pressure so it will not exceed 690 PSI, and so operate legally and safely
# With corrosion length 15.000 inch, maximum allowed corrosion depth is 0.0680 inch; A = 5.158
# With corrosion depth 0.080 inch, maximum allowed corrosion length is 11.6340 inch; A = 4.000


## Example 6
b31crvl(maop = 1e3, d = 36, wth = .5, smys = 52000, def  = 0.72, depth = 0.41, l = 100)
# Alert! Corrosion depth exceeds 80 % of pipe wall! Pipe must be replaced!
# -- Calculated data --
# Intermediate factor (A) = 21.048
# Design pressure = 1040 PSI; Safe pressure = 206 PSI
# Repair or replace pipe because corrosion depth exceeds 80 % of pipe wall!
# Reduce operating pressure so it will not exceed 206 PSI, and so operate legally and safely
# With corrosion length 100.000 inch, maximum allowed corrosion depth is 0.0630 inch; A = 21.048
# With corrosion depth 0.410 inch, maximum allowed corrosion length is 2.5560 inch; A = 0.538
# But 0.410 inch exceeds allowable corrosion depth!!!


## Example 7
b31crvl(maop = 877, d = 12.625, wth = .5, smys = 35000, def  = .4, depth = .035, l = 3)
# Corrosion depth is less than 10 % of pipe wall. No resrictions on operation
# -- Calculated data --
# Intermediate factor (A) = 1.066
# Design pressure = 1109 PSI; Safe pressure = 1109 PSI
# Pipe may be operated safely at MAOP, 877 PSI
# With corrosion length 3.000 inch, maximum allowed corrosion depth is 0.4000 inch; A = 1.066
# With corrosion depth 0.035 inch, maximum allowed corrosion length is Inf inch; A = 5.000


## Example 8
b31crvl(maop = 790, d = 24, wth = .5, smys = 42000, def  = .5, depth = .125, l = 12)
#
# -- Calculated data --
# Intermediate factor (A) = 3.093
# Design pressure = 875 PSI; Safe pressure = 845 PSI
# Pipe may be operated safely at MAOP, 790 PSI
# With corrosion length 12.000 inch, maximum allowed corrosion depth is 0.1790 inch; A = 3.093
# With corrosion depth 0.125 inch, maximum allowed corrosion length is 15.5190 inch; A = 4.000


## TEST #1
b31crvl(maop = 790, d = 24, wth = .5, smys = 42000, def  = .5, depth = .179, l = 12)
#
#-- Calculated data --
# Intermediate factor (A) = 3.093
# Design pressure = 875 PSI; Safe pressure = 791 PSI
# Pipe may be operated safely at MAOP, 790 PSI
# With corrosion length 12.000 inch, maximum allowed corrosion depth is 0.1790 inch; A = 3.093
# With corrosion depth 0.179 inch, maximum allowed corrosion length is 12.1820 inch; A = 3.140
```

```
## TEST #1A
b31crvl(maop = 790, d = 24, wth = .5, smys = 42000, def  = .5, depth = .179, l = 12.182)
#
# -- Calculated data --
# Intermediate factor (A) = 3.140
# Design pressure = 875 PSI; Safe pressure = 790 PSI
# Pipe may be operated safely at MAOP, 790 PSI
# With corrosion length 12.182 inch, maximum allowed corrosion depth is 0.1780 inch; A = 3.140
# With corrosion depth 0.179 inch, maximum allowed corrosion length is 12.1820 inch; A = 3.140


## TEST #1B
b31crvl(maop = 790, d = 24, wth = .5, smys = 42000, def  = .5, depth = .180, l = 12.182)
#
# -- Calculated data --
# Intermediate factor (A) = 3.140
# Design pressure = 875 PSI; Safe pressure = 789 PSI
# Reduce operating pressure so it will not exceed 789 PSI, and so operate legally and safely
# With corrosion length 12.182 inch, maximum allowed corrosion depth is 0.1780 inch; A = 3.140
# With corrosion depth 0.180 inch, maximum allowed corrosion length is 11.9610 inch; A = 3.083


## TEST #2
b31crvl(maop = 790, d = 24, wth = .5, smys = 42000, def  = .5, depth = .179, l = 12.297)
#
# -- Calculated data --
# Intermediate factor (A) = 3.170
# Design pressure = 875 PSI; Safe pressure = 789 PSI
# Reduce operating pressure so it will not exceed 789 PSI, and so operate legally and safely
# With corrosion length 12.297 inch, maximum allowed corrosion depth is 0.1780 inch; A = 3.170
# With corrosion depth 0.179 inch, maximum allowed corrosion length is 12.1820 inch; A = 3.140


## All examples at once:
data(b31gdata)
examples <- with(b31gdata, b31crvl(maop, d, wth, smys, def, depth, l))
```

---

b31gacd *ASME B31G. Allowable corrosion depth in pipe*

Description

Calculate allowable depth of the corroded area in the pipe.

Usage

```
b31gacd(dep, maop, d, wth, l)
```

Arguments

dep	design pressure of pipe, [*PSI*]. Type: assert_double.
maop	maximum allowable operating pressure - *MAOP*, [*PSI*]. Type: assert_double.
d	nominal outside diameter of pipe, [*inch*]. Type: assert_double.
wth	nominal wall thickness of pipe, [*inch*]. Type: assert_double.
l	measured maximum longitudinal length of corroded area, [*inch*]. Type: assert_double.

Value

allowable depth of the corroded area in the pipe, [*inch*]. Type: assert_double.

References

ASME B31G-1991. Manual for determining the remaining strength of corroded pipelines. A supplement to *ASTME B31* code for pressure piping.

See Also

Other ASME B31G functions: b31crvl(), b31gacl(), b31gafr(), b31gdep(), b31gmodpf(), b31gops(), b31gpf(), b31gsap()

Examples

```
library(pipenostics)

b31gacd(1093, 910, 30, .438, 7.5)
# [1] 0.249  # [inch]
```

---

b31gacl *ASME B31G. Allowable corrosion length in pipe*

Description

Calculate allowable length of the corroded area in the pipe.

Usage

```
b31gacl(dep, maop, d, wth, depth, l)
```

Arguments

dep	design pressure of pipe, [*PSI*]. Type: assert_double.
maop	maximum allowable operating pressure - *MAOP*, [*PSI*]. Type: assert_double.
d	nominal outside diameter of pipe, [*inch*]. Type: assert_double.
wth	nominal wall thickness of pipe, [*inch*]. Type: assert_double.
depth	measured maximum depth of the corroded area, [*inch*]. Type: assert_double.
l	measured maximum longitudinal length of the corroded area, [*inch*]. Type: assert_double.

Value

allowable length of the corroded area in the pipe, [*inch*]. Type: assert_double.

References

ASME B31G-1991. Manual for determining the remaining strength of corroded pipelines. A supplement to *ASTME B31* code for pressure piping.

See Also

Other ASME B31G functions: b31crvl(), b31gacd(), b31gafr(), b31gdep(), b31gmodpf(), b31gops(), b31gpf(), b31gsap()

Examples

```
library(pipenostics)

b31gacl(1093, 910, 30, .438, .1, 7.5)
# [1] Inf  # [inch] - corrosion is low, no limit for the corroded area length

b31gacl(438, 400, 20, .25, .18, 10)
# [1] 2.018  # [inch] - finite allowed length of the corroded area
```

---

b31gafr *ASME B31G. A-factor*

Description

Calculate intermediate factor related to the geometry of the corroded area.

Usage

```
b31gafr(d, wth, l)
```

Arguments

d	nominal outside diameter of pipe, [*inch*]. Type: assert_double.
wth	nominal wall thickness of pipe, [*inch*]. Type: assert_double.
l	measured maximum longitudinal length of the corroded area, [*inch*]. Type: assert_double.

Value

Intermediate factor related to the geometry of the corroded area, []. Type: assert_double.

References

ASME B31G-1991. Manual for determining the remaining strength of corroded pipelines. A supplement to *ASTME B31* code for pressure piping.

See Also

Other ASME B31G functions: b31crvl(), b31gacd(), b31gacl(), b31gdep(), b31gmodpf(), b31gops(), b31gpf(), b31gsap()

Examples

```
library(pipenostics)

b31gafr(30, .438, 7.5)
# [1] 1.847  # A-factor is less than 5, so the corrosion is not critical
```

---

b31gdata *ASME B31G. Corrosion state of 12 pipes*

Description

Data represents examples used for verification of computer program *CRVL.BAS* listed in *Appendix A* of ASME B31G-1991.

Usage

```
b31gdata
```

Format

A data frame with 12 rows and 15 variables:

maop maximum allowable operating pressure - *MAOP*, [*PSI*]. Type: assert_double.

d nominal outside diameter of pipe, [*inch*]. Type: assert_double.

wth nominal wall thickness of pipe, [*inch*]. Type: assert_double.

smys specified minimum yield of stress (*SMYS*) as a characteristics of steel strength, [*PSI*]. Type: assert_double.

def appropriate (combined) design factor from ASME B31.4, ASME B31.8, or ASME B31.11, []. Type: assert_double.

depth measured maximum depth of the corroded area, [*inch*]. Type: assert_double.

l measured maximum longitudinal length of corroded area, [*inch*]. Type: assert_double.

status Operational status of pipe: *1* - excellent, *2* - monitoring is recommended, *3* - alert! replace the pipe immediately! Type: assert_numeric.

design_pressure design pressure of pipe, [*PSI*]. Type: assert_double.

safe_pressure safe maximum pressure for the corroded area, [*PSI*]. Type: assert_double.

pressure_exceeding whether operator's action is required to reduce *MOAP* lower than the maximum safe pressure of the corroded area. . Type: assert_logical.

allowed_corrosion_depth allowable depth of the corroded area, [*inch*]. Type: assert_double.

A intermediate factor related to the geometry of the corroded area, []. Type: assert_double.

allowed_corrosion_length allowable length of the corroded area, [*inch*]. Type: assert_double.

AP another intermediate factor related to the geometry of the corroded area, []. Type: assert_double.

Source

https://law.resource.org/pub/us/cfr/ibr/002/asme.b31g.1991.pdf

---

b31gdep *ASME B31G. Design pressure of pipe*

Description

Calculate the design pressure that according to ASME B31G-1991 is the conditioned construction characteristic that should not in no way exceeded.

Usage

```
b31gdep(d, wth, smys, def)
```

Arguments

d	nominal outside diameter of pipe, [*inch*]. Type: assert_double.
wth	nominal wall thickness of pipe, [*inch*]. Type: assert_double.
smys	specified minimum yield of stress (*SMYS*) as a characteristics of steel strength, [*PSI*]. Type: assert_double.
def	appropriate (combined) design factor from ASME B31.4, ASME B31.8, or ASME B31.11, []. Type: assert_double.

Value

Design pressure of pipe, [*PSI*]. Type: `assert_double`.

References

ASME B31G-1991. Manual for determining the remaining strength of corroded pipelines. A supplement to *ASTME B31* code for pressure piping.

See Also

Other ASME B31G functions: `b31crvl()`, `b31gacd()`, `b31gacl()`, `b31gafr()`, `b31gmodpf()`, `b31gops()`, `b31gpf()`, `b31gsap()`

Examples

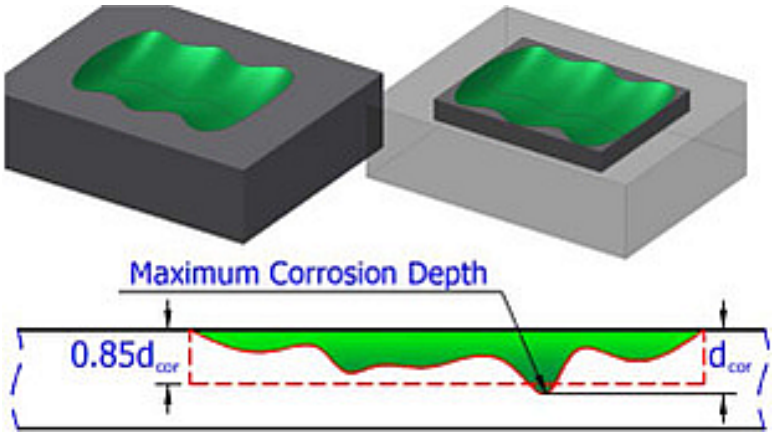
```
library(pipenostics)

b31gdep(30, .438, 52e3, .72)
# [1] 1093.748  # [PSI]
```

`b31gmodpf` *ASME B31G. Failure pressure of the corroded pipe (modified)*

Description

Calculate failure pressure of the corroded pipe according to *Modified B31G*, *Level-1* algorithm listed in ASME B31G-2012.

The next assumption of corrosion shape is adopted by *Modified B31G*:



There d*cor* represents argument `depth`.

Usage

```
b31gmodpf(d, wth, smys, depth, l)
```

Arguments

d	nominal outside diameter of pipe, [*inch*]. Type: assert_double.
wth	nominal wall thickness of pipe, [*inch*]. Type: assert_double.
smys	specified minimum yield of stress (*SMYS*) as a characteristics of steel strength, [*PSI*]. Type: assert_double.
depth	measured maximum depth of the corroded area, [*inch*]. Type: assert_double.
l	measured maximum longitudinal length of corroded area, [*inch*]. Type: assert_double.

Details

Since the definition of flow stress, *Sflow*, in ASME B31G-2012 is recommended with *Level 1* as follows:

$$Sflow = 1.1SMYS$$

no other possibilities of its evaluation are incorporated.

For this code we avoid possible semantic optimization to preserve readability and correlation with original text description in ASME B31G-2012. At the same time source code for estimated failure pressure preserves maximum affinity with its semantic description in ASME B31G-2012.

Numeric NAs may appear in case prescribed conditions of use are offended.

Value

Estimated failure pressure of the corroded pipe, [*PSI*]. Type: assert_double.

References

1. ASME B31G-2012. Manual for determining the remaining strength of corroded pipelines: supplement to *B31 Code* for pressure piping.
2. S. Timashev and A. Bushinskaya, *Diagnostics and Reliability of Pipeline Systems*, Topics in Safety, Risk, Reliability and Quality 30, **DOI 10.1007/978-3-319-25307-7**

See Also

Other fail pressure functions: b31gpf, dnvpf, shell92pf, pcorrcpf

Other ASME B31G functions: b31crvl(), b31gacd(), b31gacl(), b31gafr(), b31gdep(), b31gops(), b31gpf(), b31gsap()

Examples

```
library(pipenostics)

## Example: maximum percentage disparity of original B31G
## algorithm and modified B31G showed on CRVL.BAS data
with(b31gdata, {
  original  <- b31gpf(d, wth, smys, depth, l)
  modified  <- b31gmodpf(d, wth, smys, depth, l)
```

```
  round(max(100*abs(1 - original/modified), na.rm = TRUE), 4)
})
## Output:
#[1] 32.6666

## Example: plot disparity of original B31G algorithm and
## modified B31G showed on CRVL data
with(b31gdata[-(6:7),], {
  b31g  <- b31gpf(depth, wth, smys, depth, l)
  b31gmod  <- b31gmodpf(depth, wth, smys, depth, l)
  axe_range <- range(c(b31g, b31gmod))
  plot(b31g, b31g, type = 'b', pch = 16,
       xlab = 'Pressure, [PSI]',
       ylab = 'Pressure, [PSI]',
       main = 'Failure pressure method comparison',
       xlim = axe_range, ylim = axe_range)
  inc <- order(b31g)
  lines(b31g[inc], b31gmod[inc], type = 'b', col = 'red')
  legend('topleft',
         legend = c('B31G Original',
                    'B31G Modified'),
         col = c('black', 'red'),
         lty = 'solid')
})
```

---

b31gops *ASME B31G. Operational status of pipe*

Description

Determine the operational status of pipe: is it excellent? or is technological control required? or is it critical situation?

Usage

```
b31gops(wth, depth)
```

Arguments

wth	nominal wall thickness of pipe, [*inch*]. Type: assert_double.
depth	measured maximum depth of the corroded area, [*inch*]. Type: assert_double.

Value

Operational status of pipe as an integer value:

- *1* - excellent
- *2* - monitoring is recommended

- *3* - alert! replace the pipe immediately!

Type: `assert_numeric` and `assert_subset`.

References

ASME B31G-1991. Manual for determining the remaining strength of corroded pipelines. A supplement to *ASTME B31* code for pressure piping.

See Also

Other ASME B31G functions: `b31crvl()`, `b31gacd()`, `b31gacl()`, `b31gafr()`, `b31gdep()`, `b31gmodpf()`, `b31gpf()`, `b31gsap()`

Examples

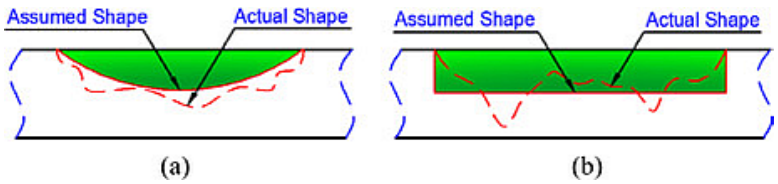
```
library(pipenostics)

b31gops(.438, .1)
# [1] 2  # typical status for the most of pipes

b31gops(.5, .41)
# [1] 3  # alert! Corrosion depth is too high! Replace the pipe!
```

`b31gpf` *ASME B31G. Failure pressure of the corroded pipe (original)*

Description

Calculate failure pressure of the corroded pipe according to *Original B31G*, *Level-1* algorithm listed in ASME B31G-2012.

The next assumption of the corrosion shape is adopted by ASME B31G-2012:



There (a) is a parabolic and (b) is a rectangular idealizations of a corroded area.

Usage

```
b31gpf(d, wth, smys, depth, l)
```

Arguments

d	nominal outside diameter of pipe, [*inch*]. Type: assert_double.
wth	nominal wall thickness of pipe, [*inch*]. Type: assert_double.
smys	specified minimum yield of stress (*SMYS*) as a characteristics of steel strength, [*PSI*]. Type: assert_double.
depth	measured maximum depth of the corroded area, [*inch*]. Type: assert_double.
l	measured maximum longitudinal length of corroded area, [*inch*]. Type: assert_double.

Details

Since the definition of flow stress, *Sflow*, in ASME B31G-2012 is recommended with *Level 1* as follows:

$$Sflow = 1.1SMYS$$

no other possibilities of its evaluation are incorporated.

For this code we avoid possible semantic optimization to preserve readability and correlation with original text description in ASME B31G-2012. At the same time source code for estimated failure pressure preserves maximum affinity with its semantic description in ASME B31G-2012 and slightly differs from that given by *Timashev et al*. The latter deviates up to 0.7 (b31gdata).

Numeric NAs may appear in case prescribed conditions of use are offended.

Value

Estimated failure pressure of the corroded pipe, [*PSI*]. Type: assert_double.

References

1. ASME B31G-2012. Manual for determining the remaining strength of corroded pipelines: supplement to *B31 Code* for pressure piping.
2. S. Timashev and A. Bushinskaya, *Diagnostics and Reliability of Pipeline Systems*, Topics in Safety, Risk, Reliability and Quality 30, **DOI 10.1007/978-3-319-25307-7**

See Also

Other fail pressure functions: b31gmodpf, dnvpf, shell92pf, pcorrcpf

Other ASME B31G functions: b31crvl(), b31gacd(), b31gacl(), b31gafr(), b31gdep(), b31gmodpf(), b31gops(), b31gsap()

Examples

```
library(pipenostics)

## Example: maximum percentage disparity of original B31G
## algorithm and modified B31G showed on CRVL.BAS data
with(b31gdata, {
  original  <- b31gpf(d, wth, smys, depth, l)
```

```
  modified  <- b31gmodpf(d, wth, smys, depth, l)
  round(max(100*abs(1 - original/modified), na.rm = TRUE), 4)
})
## Output:
#[1] 32.6666

## Example: plot disparity of original B31G algorithm and
## modified B31G showed on CRVL data
with(b31gdata[-(6:7),], {
  b31g  <- b31gpf(depth, wth, smys, depth, l)
  b31gmod  <- b31gmodpf(depth, wth, smys, depth, l)
  axe_range <- range(c(b31g, b31gmod))
  plot(b31g, b31g, type = 'b', pch = 16,
       xlab = 'Pressure, [PSI]',
       ylab = 'Pressure, [PSI]',
       main = 'Failure pressure method comparison',
       xlim = axe_range, ylim = axe_range)
  inc <- order(b31g)
  lines(b31g[inc], b31gmod[inc], type = 'b', col = 'red')
  legend('topleft',
         legend = c('B31G Original',
                    'B31G Modified'),
         col = c('black', 'red'),
         lty = 'solid')
})
```

---

b31gsap *ASME B31G. Safe maximum pressure for the corroded area of pipe*

Description

Calculate safe maximum pressure for the corroded area of pipe.

Usage

```
b31gsap(dep, d, wth, depth, l)
```

Arguments

dep	design pressure of pipe, [*PSI*]. Type: assert_double.
d	nominal outside diameter of pipe, [*inch*]. Type: assert_double.
wth	nominal wall thickness of pipe, [*inch*]. Type: assert_double.
depth	measured maximum depth of the corroded area, [*inch*]. Type: assert_double.
l	measured maximum longitudinal length of the corroded area, [*inch*]. Type: assert_double.

Value

Safe maximum pressure for the corroded area of pipe, [PSI]. Type: assert_double.

References

ASME B31G-1991. Manual for determining the remaining strength of corroded pipelines. A supplement to *ASTME B31* code for pressure piping.

See Also

Other ASME B31G functions: b31crvl(), b31gacd(), b31gacl(), b31gafr(), b31gdep(), b31gmodpf(), b31gops(), b31gpf()

Examples

```
library(pipenostics)

b31gsap(1093, 30, .438, .1, 7.5)
# [1] 1093  # [PSI], safe pressure is equal to design pressure

b31gsap(877, 24, .281, .08, 15)
# [1] 690   # [PSI], safe pressure is lower than design pressure due corrosion
```

---

c_k *Convert to Celsius scale*

Description

Convert temperature measured in Kelvin- or Fahrenheit-scale to Celsius (°*C*).

Usage

```
c_k(x)

c_f(x)
```

Arguments

x	temperature in initial scale: • for c_k(x) - in Kelvin-scale, [*K*] • for c_f(x) - in Fahrenheit-scale, [°*F*] Type: assert_double.

Value

temperature in *Celsius*-scale, [°*C*]. Type: assert_double.

See Also

k_c and f_c for converting from Celsius-scale.

Other units: f_k(), inch_mm(), k_c(), kgf_mpa(), loss_flux(), mm_inch(), mpa_kgf(), mpa_psi(), psi_mpa()

Examples

```
 library(pipenostics)

# Convert from Kelvin to Celsius:
c_k(c(0, 373.15))
# [1]  -273.15  100

# Convert from Fahrenheit to Celsius:
c_f(c(-459.67, 212))
# [1]  -273.15  100
```

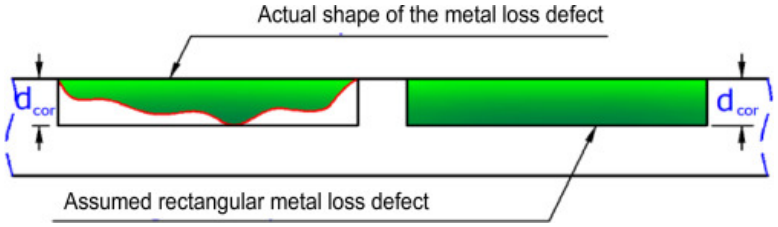
---

dnvpf *DNV-RP-F101. Failure pressure of the corroded pipe*

Description

Calculate failure pressure of the corroded pipe according to *Section 8.2* of in DNV-RP-F101. The estimation is valid for single isolated metal loss defects of the corrosion/erosion type and when only internal pressure loading is considered.

The next assumption of the corrosion shape is adopted by DNV-RP-F101:



There d*cor* represents argument depth.

Usage

```
dnvpf(d, wth, uts, depth, l)
```

Arguments

d	nominal outside diameter of pipe, [*mm*]. Type: assert_double.
wth	nominal wall thickness of pipe, [*mm*]. Type: assert_double.
uts	ultimate tensile strength (*UTS*) or specified minimum tensile strength (*SMTS*) as a characteristic of steel strength, [*MPa*]. Type: assert_double.

`depth`	measured maximum depth of the corroded area, [*mm*]. Type: `assert_double`.
`l`	measured maximum longitudinal length of corroded area, [*mm*]. Type: `assert_double`.

Details

In contrast to ASME B31G-2012 property of pipe metal is characterized by specified minimum tensile strength - *SMTS*, $[N/mm^2]$, and SI is default unit system. *SMTS* is given in the linepipe steel material specifications (e.g. API 5L) for each material grade.

At the same time *Timashev et al.* used ultimate tensile strength - UTS in place of *SMTS*. So, for the case those quantities may be used in interchangeable way.

Numeric `NA`s may appear in case prescribed conditions of use are offended.

Value

Estimated failure pressure of the corroded pipe, [*MPa*]. Type: `assert_double`.

References

1. Recommended practice DNV-RP-F101. Corroded pipelines. **DET NORSKE VERITAS**, October 2010.
2. ASME B31G-2012. Manual for determining the remaining strength of corroded pipelines: supplement to *B31 Code* for pressure piping.
3. S. Timashev and A. Bushinskaya, *Diagnostics and Reliability of Pipeline Systems*, Topics in Safety, Risk, Reliability and Quality 30, **DOI 10.1007/978-3-319-25307-7**.

See Also

Other fail pressure functions: `b31gpf`, `b31gmodpf`, `shell92pf`, `pcorrcpf`

Other DNV-RP-F101 functions: `strderate()`

Examples

```
 library(pipenostics)

d     <- c(812.8, 219.0)  # [mm]
wth   <- c( 19.1,  14.5)  # [mm]
uts   <- c(530.9, 455.1)  # [N/mm^2]
l     <- c(203.2, 200.0)  # [mm]
depth <- c( 13.4,   9.0)  # [mm]

dnvpf(d, wth, uts, depth, l)
# [1] 15.86626 34.01183
```

dropg *Flow rate drop in pipe*

Description

Calculate *drop* or *recovery* of flow rate in pipe using geometric factors.

The calculated value may be positive or negative. When it is positive they have the *drop*, i.e. the decrease of flow rate in the outlet of pipe under consideration. When the calculated value is negative they have the *recovery*, i.e. the increase of flow rate in the outlet of pipe under consideration. In both cases to calculate flow rate on the outlet of pipe under consideration simply subtract the calculated value from the sensor-measured flow rate on the inlet.

Usage

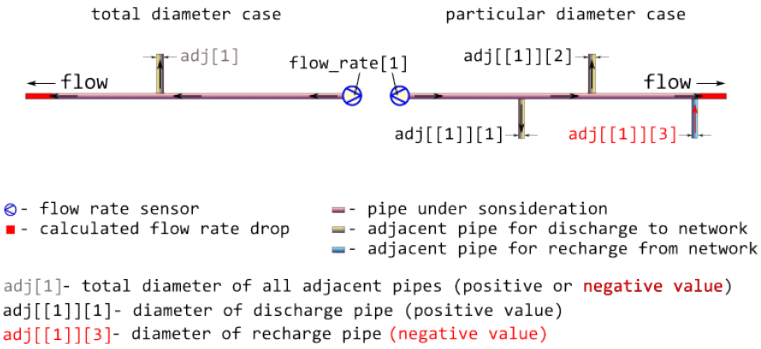
```
dropg(adj = 0, d = 700, flow_rate = 250)
```

Arguments

adj	diameters of adjacent pipes through which discharges to and recharges from network occur, [*mm*]. Types: assert_double total diameter of all adjacent pipes (total diameter case) assert_list **of** assert_double a set of diameters of adjacent pipes (particular diameter case) Positive values of diameters of adjacent pipes correspond to discharging process through those pipe, whereas negative values of diameters mean recharging. See **Details** and **Examples** for further explanations.
d	diameter of pipe under consideration, [*mm*]. Type: assert_double.
flow_rate	sensor-measured amount of heat carrier (water) that is transferred through the inlet of pipe during a period, [*ton/hour*]. Type: assert_double.

Details

It is common that sensor-measured flow rate undergoes discharges to network and recharges from it. For calculation of flow rate *drop* or *recovery* the next configuration of district heating network segment is assumed:



Usually, there are no additional sensors that could measure flow rate in each flow fork. In that case they only may operate with geometric factors, i.e. assuming that flow rate is proportional to square of pipe diameter.

The simple summation of flow rates over all adjacent pipes produces the required flow rate *drop* or *recovery* located on the outlet of the pipe under consideration. Since there is concurrency between discharges and recharges the diameters of discharge pipes are regarded positive whereas diameters of recharge pipes must be negative.

Be careful when dealing with geometric factors for large amount of recharges from network: there are no additional physical constraints and thus the calculated value of *recovery* may have non-sense.

Value

flow rate *drop* or *recovery* at the outlet of pipe, [*ton/hour*], numeric vector. The value is positive for *drop*, whereas for *recovery* it is negative. In both cases to calculate flow rate on the outlet of pipe under consideration simply subtract the calculated value from the sensor-measured flow rate on the inlet. Type: `assert_double`.

See Also

Other district heating: `dropp()`, `dropt()`

Examples

```
 library(pipenostics)

# Let consider pipes according to network segment scheme depicted in figure
# in [?dropg] help-page.

# Typical large diameters of pipes under consideration, [mm]:
d <- as.double(unique(subset(pipenostics::m325nhldata, diameter > 700)$diameter))

# Let sensor-measured flow rate in the inlet of pipe
# under consideration be proportional to d, [ton/hour]:
flow_rate <- .125*d

# Let consider total diameter case when total diameters of adjacent pipes are no
# more than d, [mm]:
```

```
adj <- c(450, -400, 950, -255, 1152)

# As at may be seen for the second and fourth cases they predominantly have
# recharges from network.
# Let calculate flow rate on the outlet of the pipe under consideration,
# [ton/hour]

result <- flow_rate - dropg(adj, d, flow_rate)
print(result)

# [1]  75.96439 134.72222  65.70302 180.80580  78.05995

# For more clarity they may perform calculations in `data.table`.
```

---

dropp *Pressure drop in pipe*

Description

Calculate pressure drop in straight cylidrical steel pipe of *district heating system* (where water is a heat carrier) that is a result of pipe orientation in space (hydrostatic component), and friction between water and internal wall of pipe.

Usage

```
dropp(
  temperature = 130,
  pressure = mpa_kgf(6),
  flow_rate = 1276,
  d = 1,
  len = 1,
  roughness = 0.006,
  inlet = 0,
  outlet = 0,
  method = "romeo"
)
```

Arguments

`temperature`	temperature of heat carrier (water) inside the pipe, [$°C$]. Type: `assert_double`.
`pressure`	absolute pressure of heat carrier (water) measured at the entrance (inlet) of pipe, [*MPa*]. Type: `assert_double`.
`flow_rate`	amount of heat carrier (water) that is transferred by pipe during a period, [*ton/hour*]. Type: `assert_double`.
`d`	internal diameter of pipe, [m]. Type: `assert_double`.
`len`	pipe length, [m]. Type: `assert_double`.
`roughness`	roughness of internal wall of pipe, [m]. Type: `assert_double`.

`inlet`	elevation of pipe inlet, [m]. Type: `assert_double`.
`outlet`	elevation of pipe outlet, [m]. Type: `assert_double`.
`method`	method of determining *Darcy friction factor*. Type: `assert_choice`. (see **Details**)

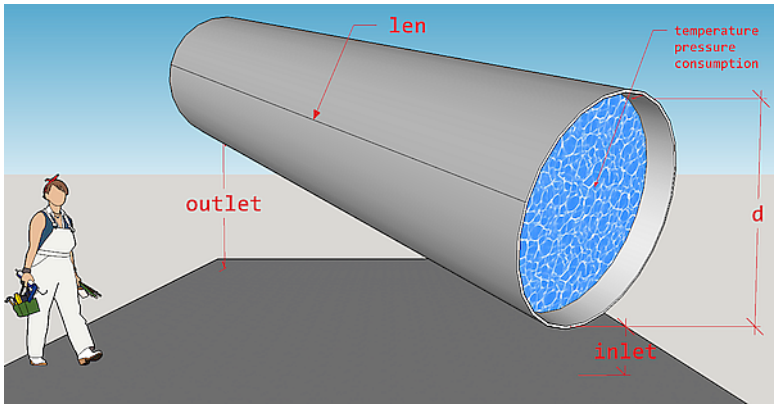
Details

The underlying engineering model for calculation of pressure drop considers only two contributions (components):

1. Pressure drop due to gravity (hydrostatic component).
2. Pressure drop due to friction.

The model does not consider any size changes of pipe and presence of fittings.

For the first component that depends on pipe position in space the next figure illustrates adopted disposition of pipe.



So, the expression for the first component can be written as:

$$g\rho(outlet - inlet)$$

where g - is gravity factor, m/s^2, and ρ - density of water (heat carrier), kg/m^3; `inlet` and `outlet` are appropriate pipe elevations (under sea or any other adopted level), m.

The second component comes from Darcy–Weisbach equation and is calculated using heating carrier regime parameters (`temperature`, `pressure`, `flow_rate`). Temperature and pressure values of heat carrier define water properties according to IAPWS formulation.

Several methods for calculating of *Darcy friction factor* are possible and limited to the next direct approximations of Colebrook equation:

romeo Romeo, Royo and Monzon, 2002

vatankhan Vatankhan and Kouchakzadeh, 2009

buzelli Buzzelli, 2008

According to *Brkic, 2011* approximations errors of those methods do not exceed `0.15` % for the most combinations of Reynolds numbers and actual values of internal wall roughness of pipe.

Value

pressure drop at the outlet of pipe, [*MPa*]. Type: assert_double.

References

- W.Wagner et al. *The IAPWS Industrial Formulation 1997 for the Thermodynamic Properties of Water and Steam*, J. Eng. Gas Turbines Power. Jan 2000, **122**(1): *150-184* (35 pages)
- M.L.Huber et al.*New International Formulation for the Viscosity of H_2O*, Journal of Physical and Chemical Reference Data **38**, 101 (2009);
- D.Brkic. *Journal of Petroleum Science and Engineering*, Vol. **77**, *Issue 1*, April 2011, Pages *34-48*.
- Romeo, E., Royo, C., Monzon, A., 2002. *Improved explicit equation for estimation of friction factor in rough and smooth pipes.* Chem. Eng. J. **86** (3), *369–374*.
- Vatankhah, A.R., Kouchakzadeh, S., 2009. *Discussion: Exact equations for pipeflow problems, by P.K. Swamee and P.N. Rathie*. J. Hydraul. Res. IAHR **47** (7), *537–538*.
- Buzzelli, D., 2008. *Calculating friction in one step*. Mach. Des. **80** (12), *54–55*.

See Also

dropt for calculating temperature drop in pipe

Other district heating: dropg(), dropt()

Examples

```
 library(pipenostics)

# Typical pressure drop for horizontal pipeline segments
# in high-way heating network in Novosibirsk
dropp(len = c(200, 300))

#[1] 0.0007000666 0.0010500999
```

---

dropt *Temperature drop in cylindrical steel pipe due heat loss*

Description

Calculate temperature drop in steel pipe of *district heating system* (where water is a heat carrier) that is a result of heat loss through pipe wall and insulation.

Usage

```
dropt(
  temperature = 130,
  pressure = mpa_kgf(6),
  flow_rate = 250,
  loss_power = 7000
)
```

Arguments

temperature	temperature of heat carrier (water) inside the pipe measured at the inlet of pipe, [°*C*]. Type: assert_double.
pressure	absolute pressure of heat carrier (water) inside the pipe, [*MPa*]. Type: assert_double.
flow_rate	amount of heat carrier (water) that is transferred by pipe during a period, [*ton/hour*]. Type: assert_double.
loss_power	power of heat loss - heat loss through area of pipe wall per hour, [*kcal/hour*]. Type: assert_double.

Details

Specific isobaric heat capacity used in calculations is calculated according to IAPWS R7-97(2012) for **Region 1** since it is assumed that state of water in *district heating system* is always in that region.

Value

temperature drop at the outlet of pipe, [°*C*]. Type: assert_double.

See Also

Other district heating: dropg(), dropp()

Examples

```
library(pipenostics)

# Calculate normative temperature drop based on Minenergo-325 for pipe segment
pipeline <- list(
  year   = 1968,
  laying = "channel",
  d      = 700, # [mm]
  len    = 1000 # [m]
)

regime <- list(
  temperature = c(130, 150), # [°C]
  pressure    = .588399,     # [MPa]
  flow_rate   = 250          # [ton/hour]
)

pipe_loss_power <- do.call(
```

```
    m325nhl,
   c(pipeline, temperature = list(regime[["temperature"]]), duration = 1)  # [kcal/hour]
)

temperature_drop <- dropt(
  temperature = regime[["temperature"]], # [°C]
  loss_power  = pipe_loss_power          # [kcal/hour]
)                                        # [°C]

print(temperature_drop)

# [1] 1.366806 1.433840
```

`flowls` *List all possible flow paths in district heating network*

Description

Find and list all possible paths of heat carrier flow (water) in the given topology of district heating system.

Usage

```
flowls(sender = "A", acceptor = "B", use_cluster = FALSE)
```

Arguments

`sender`	identifier of the node which heat carrier flows out. Type: any type that can be painlessly coerced to character by `as.character`.
`acceptor`	identifier of the node which heat carrier flows in. According to topology of test bench considered this identifier should be unique. Type: any type that can be painlessly coerced to character by `as.character`.
`use_cluster`	utilize functionality of parallel processing on multi-core CPU. Type: `assert_flag`.

Details

Only branched topology without cycles is considered where no more than one incoming edge exists for every `acceptor` node. For instance, `m325testbench` has permitted topology.

Though input arguments are natively vectorized their individual values all relate to common part of district heating network, i.e. associated with common object. It is due to isomorphism between vector representation and directed graph of this network. For more details of isomorphic topology description see `m325testbench`.

Value

named `list` that contains integer vectors as its elements. The name of each element in the `list` is the name of `acceptor` associated with terminal node of district heating network. Each vector in the `list` represents an ordered sequence of indexes in `acceptor` that enumerates incoming edges from starting node to terminal one. The length of returned `list` is equal to number of terminal nodes for topology considered. Type: `assert_list`.

See Also

`m325testbench` for example of topology of district heating system

Examples

```
 library(pipenostics)


# Find path from A to B in trivial line topology:
flowls("A", "B")

# $B
# [1] 1

# More complex example with two terminal nodes D and E:
flowls(c("A", "B", "B"), c("B", "D", "E"))

#$D
#[1] 1 2
#
#$E
#[1] 1 3

# All possible flow paths in test bench illustrated in `?m325testbench`:
all_paths <- list(
  c(12, 13, 11, 8, 4, 1),  # hereinafter indexes of acceptor nodes
  c(12, 13, 11, 8, 4, 2),
  c(12, 13, 11, 8, 6, 5,  3),
  c(12, 13, 11, 8, 6, 7),
  c(12, 13, 11, 8, 6, 9),
  c(12, 13, 11, 10),
  c(12, 13, 14, 15),
  c(12, 13, 16, 17),
  c(12, 13, 16, 18, 20, 19),
  c(12, 13, 16, 18, 20, 21),
  c(12, 13, 16, 18, 22, 24),
  c(12, 13, 16, 18, 22, 25),
  c(12, 13, 16, 18, 20, 23, 26)
)

# find those paths:
path <- with(pipenostics::m325testbench, {
  flowls(sender, acceptor)
})
```

```
path[[4]]
# [1] 12 13 11  8  6  7
```

`fric_buzelli` *Estimate pipe friction factor with Buzelli formula*

Description

Estimate *Darcy friction factor* explicitly with extremely accurate *Buzelli* approximation of *Colebrook equation*.

Usage

```
fric_buzelli(reynolds, roughness = 0, strict = FALSE)
```

Arguments

`reynolds`	Reynolds number, []. Type: `assert_double`.
`roughness`	relative roughness, []. Type: `assert_double`.
`strict`	calculate only inside the precision region. Type: `assert_flag`.

Details

Buzelli's formula is reported to be extremely accurate in the region:

- `3.0e3` <= `reynolds` <= `3.0e8`
- `0` <= `roughness` <= `0.05`

In `strict` = `TRUE` mode argument values outside this precision region are not allowed, whereas in `strict` = `FALSE` either *NA*s are generated in that case or calculation for laminar flow is performed when `reynolds` < `2100.0`.

Value

pipe friction factor, []. Type: `assert_double`.

References

1. Offor, U. and Alabi, S. (2016) *An Accurate and Computationally Efficient Explicit Friction Factor Model*. Advances in Chemical Engineering and Science, *6*, pp. 237-245. doi:10.4236/aces.2016.63024.
2. Buzzelli, D. (2008) *Calculating friction in one step*. Machine Design, *80* (12), pp. 54–55.

See Also

Other Fluid properties: `fric_romeo()`, `fric_vatankhan()`, `re_u()`

Examples

```
library(pipenostics)

fric_buzelli(c(2118517, 2000, 2118517), c(1e-6, 70e-3/1, 7e-3/1))
# [1] 0.01031468 0.03200000 0.03375076  # []

fric_buzelli(c(2118517, 5500, 2118517), c(1e-6, 50e-3/1, 7e-3/1), TRUE)
# [1] 0.01031468 0.07556734 0.03375076
```

`fric_romeo` *Estimate pipe friction factor with Romeo's formula*

Description

Estimate *Darcy friction factor* explicitly with extremely accurate *Romeo-Royo-Monzón* approximation of *Colebrook equation*.

Usage

```
fric_romeo(reynolds, roughness = 0, strict = FALSE)
```

Arguments

`reynolds`	Reynolds number, []. Type: `assert_double`.
`roughness`	relative roughness, []. Type: `assert_double`.
`strict`	calculate only inside the precision region. Type: `assert_flag`.

Details

Romeo's formula is reported to be extremely accurate in the region:

- `3.0e3` <= `reynolds` <= `1.5e8`
- `0.0` <= `roughness` <= `0.05`

In `strict` = `TRUE` mode argument values outside this precision region are not allowed, whereas in `strict` = `FALSE` either *NA*s are generated in that case or calculation for laminar flow is performed when `reynolds` < `2100.0`.

Value

pipe friction factor, []. Type: `assert_double`.

References

1. Offor, U. and Alabi, S. (2016) *An Accurate and Computationally Efficient Explicit Friction Factor Model*. Advances in Chemical Engineering and Science, *6*, pp. 237-245. doi:10.4236/aces.2016.63024.
2. Eva Romeo, Carlos Royo, Antonio Monzón, *Improved explicit equations for estimation of friction factor in rough and smooth pipes*, Chemical Engineering Journal, *Volume 86*, Issue 3, 2002, Pages 369-374, ISSN 1385-8947. doi:10.1016/S13858947(01)002546.

See Also

Other Fluid properties: `fric_buzelli()`, `fric_vatankhan()`, `re_u()`

Examples

```
library(pipenostics)

fric_romeo(c(2118517, 2000, 2118517), c(0, 70e-3/1, 7e-3/1))
# [1] 0.01028473 0.03200000 0.03373215  # []

fric_romeo(c(2118517, 3030, 2118517), c(0, 50e-3/1, 7e-3/1), TRUE)
# [1] 0.01028473 0.07859636 0.03373215  # []
```

`fric_vatankhan` *Estimate pipe friction factor with Vatankhah formula*

Description

Estimate *Darcy friction factor* explicitly with extremely accurate *Vatankhah-Kouchakzadeh* approximation of *Colebrook equation*.

Usage

```
fric_vatankhan(reynolds, roughness = 0, strict = FALSE)
```

Arguments

`reynolds`	Reynolds number, []. Type: `assert_double`.
`roughness`	relative roughness, []. Type: `assert_double`.
`strict`	calculate only inside the precision region. Type: `assert_flag`.

Details

Vatankhah's formula is reported to be extremely accurate in the region:

- `5.0e3` <= `reynolds` <= `1.0e8`
- `1e-6` <= `roughness` <= `0.05`

In `strict` = `TRUE` mode argument values outside this precision region are not allowed, whereas in `strict` = `FALSE` either *NA*s are generated in that case or calculation for laminar flow is performed when `reynolds` < `2100.0`.

Value

pipe friction factor, []. Type: `assert_double`.

References

1. Offor, U. and Alabi, S. (2016) *An Accurate and Computationally Efficient Explicit Friction Factor Model*. Advances in Chemical Engineering and Science, *6*, pp. 237-245. doi:10.4236/aces.2016.63024.
2. Ali R. Vatankhah, Salah Kouchakzadeh (2009) *Exact equations for pipe-flow problems*. Journal of Hydraulic Research, *47:4*, pp. 537-538, DOI: doi:10.1080/00221686.2009.9522031

See Also

Other Fluid properties: `fric_buzelli()`, `fric_romeo()`, `re_u()`

Examples

```
library(pipenostics)

fric_vatankhan(c(2118517, 2000, 2118517), c(1e-6, 70e-3/1, 7e-3/1))
# [1] 0.01031665 0.03200000 0.03375210  # []

fric_vatankhan(c(2118517, 5500, 2118517), c(1e-6, 50e-3/1, 7e-3/1), TRUE)
# [1] 0.01031665 0.07556163 0.03375210
```

`f_k` *Convert to Fahrenheit scale*

Description

Convert temperature measured in Kelvin- or Celsius-scale to Fahrenheit (°*F*).

Usage

```
f_k(x)

f_c(x)
```

Arguments

`x`	temperature in initial scale: • for `f_k(x)` - in Kelvin-scale, [*K*] • for `f_c(x)` - in Celsius-scale, [°*C*] Type: `assert_double`.

Value

temperature in *Fahrenheit*-scale, [°*F*]. Type: `assert_double`.

See Also

k_f and c_f for converting from Fahrenheit-scale.

Other units: c_k(), inch_mm(), k_c(), kgf_mpa(), loss_flux(), mm_inch(), mpa_kgf(), mpa_psi(), psi_mpa()

Examples

```
 library(pipenostics)

# Convert from Kelvin to Fahrenheit:
f_k(c(0, 373.15))
# [1]  -459.67 212

# Convert from Celsius to Fahrenheit:
f_c(c(-273.15, 100))
# [1]  -459.67, 212
```

---

geoarea *Calculate geographical metrics*

Description

Calculate geographical metrics (distance, area) for two or three geographical locations.

Usage

```
geoarea(lat1, lon1, lat2, lon2, lat3, lon3, earth = 6371008.7714)

geodist(lat1, lon1, lat2, lon2, earth = 6371008.7714)
```

Arguments

lat1	latitude of the first geographical location, [*DD*]. Type: assert_double.
lon1	longitude of the first geographical location, [*DD*]. Type: assert_double.
lat2	latitude of the second geographical location, [*DD*]. Type: assert_double.
lon2	longitude of the second geographical location, [*DD*]. Type: assert_double.
lat3	latitude of the third geographical location, [*DD*]. Type: assert_double.
lon3	longitude of the third geographical location, [*DD*]. Type: assert_double.
earth	*Earth* radius, [*m*]. See **Details**. Type: assert_numeric.

Details

`geodist` calculates distance between two geographical locations on *Earth*, whereas `geoarea` calculates the area of spherical triangle between three geographical locations. Both functions use absolute positions of geographical locations described by geographical coordinate system in decimal degrees units denoted as *DD*. The haversine formula is applied to calculate the distance, and so the spherical model of *Earth* is considered in both functions.

Since several variants of *Earth* radius can be accepted, the user is welcome to provide its own value. WGS-84 mean radius of semi-axes, R_1, is the default value.

The resulting distance is expressed in metres (*m*), whereas the area is expressed in square kilometers(*km^2*).

Value

For `geodist`: distance between two geographical locations, [*m*].

For `geoarea`: area of spherical triangle between three geographical locations, [*km^2*].

Type: `assert_double`.

See Also

Other utils: `meteos()`, `mgtdhid()`, `wth_d()`

Examples

```
library(pipenostics)

# Consider the longest linear pipeline segment in Krasnoyarsk, [DD]:
pipe <- list(
  lat1 = 55.98320350, lon1 = 92.81257226,
  lat2 = 55.99302417, lon2 = 92.80691885
)

# and some official Earth radii, [m]:
R <- c(
  nominal_zero_tide_equatorial = 6378100.0000,
  nominal_zero_tide_polar      = 6356800.0000,
  equatorial_radius            = 6378137.0000,
  semiminor_axis_b             = 6356752.3141,
  polar_radius_of_curvature    = 6399593.6259,
  mean_radius_R1               = 6371008.7714,
  same_surface_R2              = 6371007.1810,
  same_volume_R3               = 6371000.7900,
  WGS84_ellipsoid_axis_a       = 6378137.0000,
  WGS84_ellipsoid_axis_b       = 6356752.3142,
  WGS84_ellipsoid_curvature_c  = 6399593.6258,
  WGS84_ellipsoid_R1           = 6371008.7714,
  WGS84_ellipsoid_R2           = 6371007.1809,
  WGS84_ellipsoid_R3           = 6371000.7900,
  GRS80_axis_a                 = 6378137.0000,
  GRS80_axis_b                 = 6356752.3141,
  spherical_approx             = 6366707.0195,
```

```
  meridional_at_the_equator    = 6335439.0000,
  Chimborazo_maximum           = 6384400.0000,
  Arctic_Ocean_minimum         = 6352800.0000,
  Averaged_center_to_surface   = 6371230.0000
)

# Calculate length of the pipeline segment for different radii:
len <- with(
  pipe, vapply(
    R, geodist, double(1), lat1 = lat1, lon1 = lon1, lat2 = lat2, lon2 = lon2
  )
)

print(range(len))

# [1] 1140.82331483 1152.37564656 #  [m]


# Consider some remarkable objects on Earth, [DD]:
objects <- rbind(
  Mount_Kailash      = c(lat = 31.069831297551982, lon =  81.31215667724196),
  Easter_Island_Moai = c(lat =-27.166873910247862, lon =-109.37092217323053),
  Great_Pyramid      = c(lat = 29.979229451772856, lon =  31.13418110843685),
  Antarctic_Pyramid  = c(lat = -79.97724194984573, lon = -81.96170583068950),
  Stonehendge        = c(lat = 51.179036665131870, lon =-1.8262150017463086)
)

# Consider all combinations of distances between them:
path <- t(combn(rownames(objects), 2))

d <- geodist(
  lat1 = objects[path[, 1], "lat"],
  lon1 = objects[path[, 1], "lon"],
  lat2 = objects[path[, 2], "lat"],
  lon2 = objects[path[, 2], "lon"]
)*1e-3

cat(
  paste(
    sprintf("%s <--- %1.4f km ---> %s", path[, 1], d, path[, 2]),
    collapse = "\n"
)
)

# Consider two areas
#         * Bermuda triangle     * Polynesian Triangle
lat1 <- c(Miami   =  25.789106,  Hawaii       =   19.820680)
lon1 <- c(Miami   = -80.226529,  Hawaii       = -155.467989)

lat2 <- c(Bermuda =  32.294887,  NewZeland    =  -43.443219)
lon2 <- c(Bermuda = -64.781380,  NewZeland    =  170.271360)

lat3 <- c(SanJuan =  18.466319,  EasterIsland =  -27.112701)
```

```
lon3 <- c(SanJuan = -66.105743,  EasterIsland = -109.349668)

# Area provided by manually operated Google Earth:
GETriangleArea <- c(
  Bermuda    =  1147627.48,  # [km^2]
  Polynesian = 28775517.77   # [km^2]
)

# Show the discrepancy in calculations, [km^2]:
print(geoarea(lat1, lon1, lat2, lon2, lat3, lon3))

 #   Bermuda Polynesian
 # 0.4673216 11.1030971
```

---

inch_mm *Millimeters to inches*

Description

Convert length measured in millimeters (mm) to inches

Usage

```
inch_mm(x)
```

Arguments

x	length measured in *millimeters*, [*mm*]. Type: assert_double.

Value

length in *inches*, [*inch*]. Type: assert_double.

See Also

mm_inch for converting *inches* to *mm*

Other units: c_k(), f_k(), k_c(), kgf_mpa(), loss_flux(), mm_inch(), mpa_kgf(), mpa_psi(), psi_mpa()

Examples

```
library(pipenostics)

inch_mm(c(25.4, 1))
# [1] 1.00000000 0.03937008  # [inch]
```

kgf_mpa *Megapascals to kilogram-force per square*

Description

Convert pressure (stress) measured in megapascals (MPa) to kilogram-force per square cm (kgf/cm^2).

Usage

```
kgf_mpa(x)
```

Arguments

x	pressure (stress) measured in *megapascals*, [*MPa*]. Type: assert_double.

Value

pressure (stress) in *kilogram-force per square cm*, [*kgf/cm^2*]. Type: assert_double.

See Also

mpa_kgf for converting *kilogram-force per square cm* to *megapascals*

Other units: c_k(), f_k(), inch_mm(), k_c(), loss_flux(), mm_inch(), mpa_kgf(), mpa_psi(), psi_mpa()

Examples

```
library(pipenostics)

kgf_mpa(c(0.0980665, 1))
# [1]  1.00000 10.19716
```

k_c *Covert to Kelvin scale*

Description

Convert temperature measured in Celsius- or Fahrenheit-scale to Kelvin (*K*).

Usage

```
k_c(x)

k_f(x)
```

Arguments

x	temperature in initial scale: • for k_c(x) - in Celsius-scale, [°C] • for k_f(x) - in Fahrenheit-scale, [°F] Type: assert_double.

Value

temperature in *Kelvin*-scale, [*K*]. Type: assert_double.

See Also

c_k and f_k for converting from Kelvin-scale.

Other units: c_k(), f_k(), inch_mm(), kgf_mpa(), loss_flux(), mm_inch(), mpa_kgf(), mpa_psi(), psi_mpa()

Examples

```
 library(pipenostics)

# Convert from Celsius to Kelvin:
k_c(c(-273.15, 100))
# [1]  0  373.15

# Convert from Fahrenheit to Kelvin:
k_f(c(-459.67, 212))
# [1]  0  373.15
```

---

loss_flux *Convert heat flux to specific heat loss power*

Description

Convert heat flux measured for a cylindrical steel pipe to *specific heat loss power* of pipe.

Usage

```
loss_flux(x, d, wth = 0)

flux_loss(x, d, wth = 0)
```

Arguments

x	value of • *heat flux*, [*W/m^2*], for `loss_flux(x, d, wth)` • *specific heat loss power*, [*kcal/m/h*], for `flux_loss(x, d, wth)(x)` Type: assert_double.
d	outside (if *wth = 0*) or internal (if *wth > 0*) diameter of cylindrical pipe, [*m*]. Type: assert_double.
wth	wall thickness of pipe, [*mm*], or *0* if argument *d* is an outside diameter of pipe. Type: assert_double.

Value

value of

- *specific heat loss power*, [*kcal/m/h*], for `loss_flux(x, d, wth)`
- *heat flux*, [*W/m^2*], for `flux_loss(x, d, wth)(x)`

Type: assert_double.

See Also

Other units: c_k(), f_k(), inch_mm(), k_c(), kgf_mpa(), mm_inch(), mpa_kgf(), mpa_psi(), psi_mpa()

Examples

```
library(pipenostics)

# Consider pipes:
diameter      <- c(998, 1395)  # [mm]
wall_thikness <- c(  2,    5)  # [mm]

# Then maximum possible normative neat loss according (Minenergo-325) for
# these pipe diameters are
loss_max <- c(218, 1040)  # [kcal/m/h]

# The appropriate flux is
flux <- flux_loss(loss_max, diameter * 1e-3, wall_thikness)
print(flux)

# [1] 80.70238 275.00155  # [W/m^2]

stopifnot(
  all.equal(loss_flux(flux, diameter * 1e-3, wall_thikness), loss_max, tolerance = 5e-6)
)
```

`m278hlair` *Minenergo-278. Normative heat loss of open-air pipe*

Description

Calculate normative heat loss of the open-air supplying pipe as a function of construction, operation, and technical condition specifications according to Appendix 5.1 of Minenergo Method 278.

This type of calculations is usually made on design stage of district heating network (where water is a heat carrier) and is closely related to building codes and regulations.

Usage

```
m278hlair(
  t1 = 110,
  t2 = 60,
  t0 = 5,
  insd1 = 0.1,
  insd2 = insd1,
  d1 = 0.25,
  d2 = d1,
  lambda1 = 0.09,
  lambda2 = 0.07,
  k1 = 1,
  k2 = k1,
  lambda0 = 26,
  len = 1,
  duration = 1
)
```

Arguments

`t1`	temperature of heat carrier (water) inside the supplying pipe, [$°C$]. Type: `assert_double`.
`t2`	temperature of heat carrier (water) inside the returning pipe, [$°C$]. Type: `assert_double`.
`t0`	temperature of environment, [$°C$]. In case of open-air pipe this is the ambient temperature. Type: `assert_double`.
`insd1`	thickness of the insulator which covers the supplying pipe, [m]. Type: `assert_double`.
`insd2`	thickness of the insulator which covers the returning pipe, [m]. Type: `assert_double`.
`d1`	outside diameter of supplying pipe, [m]. Type: `assert_double`.
`d2`	outside diameter of returning pipe, [m]. Type: `assert_double`.
`lambda1`	thermal conductivity of insulator which covers the supplying pipe [$W/m/°C$]. Type: `assert_double`.
`lambda2`	thermal conductivity of insulator which covers the returning pipe [$W/m/°C$]. `assert_double`.
`k1`	technical condition factor for insulator of supplying pipe, []. Type: `assert_double`.

k2	technical condition factor for insulator of returning pipe, []. Type: assert_double.
lambda0	thermal conductivity of environment, [*W/m/°C*]. In case of overhead laying this is the thermal conductivity of open air. Type: assert_double.
len	length of supplying pipe, [*m*]. Type: assert_double.
duration	duration of heat loss, [*hour*]. Type: assert_double.

Details

Details on using k1 and k2 are the same as for m278hlcha.

Value

Normative heat loss of the open-air layed supplying cylindrical pipe during duration, [*kcal*]. If len of pipe is 1 *m* (meter) as well as duration is set to 1 *h* (hour) (default values) then the return value is also the *specific heat loss power*, [*kcal/m/h*] and so comparable with those prescribed by Minenergo Order 325. Type: assert_double.

See Also

Other Minenergo: m278hlcha(), m278hlund(), m278insdata, m278inshcm(), m278soildata, m325beta(), m325nhl(), m325nhldata, m325testbench

Examples

```
library(pipenostics)

m278hlair()
# [1] 138.7736
```

---

m278hlcha *Minenergo-278. Normative heat loss of pipe in channel*

Description

Calculate normative heat loss of the supplying pipe mounted in underground channel as a function of construction, operation, and technical condition specifications according to Appendix 5.1 of Minenergo Method 278.

This type of calculations is usually made on design stage of district heating network (where water is a heat carrier) and is closely related to building codes and regulations.

Usage

```
m278hlcha(
  t1 = 110,
  t2 = 60,
  t0 = 5,
  insd1 = 0.1,
  insd2 = insd1,
  d1 = 0.25,
  d2 = d1,
  lambda1 = 0.09,
  lambda2 = 0.07,
  k1 = 1,
  k2 = k1,
  lambda0 = 1.74,
  z = 2,
  b = 0.5,
  h = 0.5,
  len = 1,
  duration = 1
)
```

Arguments

t1	temperature of heat carrier (water) inside the supplying pipe, [$°C$]. Type: assert_double.
t2	temperature of heat carrier (water) inside the returning pipe, [$°C$]. Type: assert_double.
t0	temperature of environment, [$°C$]. In case of channel laying this is the temperature of subsoil. Type: assert_double.
insd1	thickness of the insulator which covers the supplying pipe, [m]. Type: assert_double.
insd2	thickness of the insulator which covers the returning pipe, [m]. Type: assert_double.
d1	outside diameter of supplying pipe, [m]. Type: assert_double.
d2	outside diameter of returning pipe, [m]. Type: assert_double.
lambda1	thermal conductivity of insulator which covers the supplying pipe [$W/m/°C$]. Type: assert_double.
lambda2	thermal conductivity of insulator which covers the returning pipe [$W/m/°C$]. Type: assert_double.
k1	technical condition factor for insulator of supplying pipe, []. Type: assert_double.
k2	technical condition factor for insulator of returning pipe, []. Type: assert_double.
lambda0	thermal conductivity of environment, [$W/m/°C$]. In case of channel laying this is the thermal conductivity of subsoil. Type: assert_double.
z	channel laying depth, [m]. Type: assert_double.
b	channel width, [m]. Type: assert_double.
h	channel height, [m]. Type: assert_double.
len	length of supplying pipe, [m]. Type: assert_double.
duration	duration of heat loss, [$hour$]. Type: assert_double.

Details

k1 and k2 factor values equal to 1 mean the best technical condition of insulation of appropriate pipes, whereas for poor technical state factor values tends to 5 or more.

Nevertheless, when k1 and k2 both equal to 1 the calculated *specific heat loss power* [*kcal/m/h*] is sometimes higher than that listed in Minenergo Order 325. One should consider that situation when choosing method for heat loss calculations.

Value

Normative heat loss of supplying cylindrical pipe mounted in channel during duration, [*kcal*]. If len of pipe is 1 *m* (meter) as well as duration is set to 1 *h* (hour) (default values) then the return value is also the *specific heat loss power*, [*kcal/m/h*] and so comparable with those prescribed by Minenergo Order 325. Type: assert_double.

See Also

Other Minenergo: m278hlair(), m278hlund(), m278insdata, m278inshcm(), m278soildata, m325beta(), m325nhl(), m325nhldata, m325testbench

Examples

```
library(pipenostics)

m278hlcha()
#

## Naive way to find out technical state (factors k1 and k2) for pipe
## segments constructed in 1980:
  optim(
    par = c(1.5, 1.5),
    fn = function(x) {
    # functional to optimize
      abs(
          m278hlcha(k1 = x[1], k2 = x[2]) -
          m325nhl(year = 1980, laying = "channel", d = 250, temperature = 110)
      )
    },
    method = "L-BFGS-B",
    lower = 1.01, upper = 4.4
  )$par
  # [1] 4.285442 4.323628
```

Description

Calculate normative heat loss of the supplying underground pipe as a function of construction, operation, and technical condition specifications according to Appendix 5.1 of Minenergo Method 278.

This type of calculations is usually made on design stage of district heating network (where water is a heat carrier) and is closely related to building codes and regulations.

Usage

```
m278hlund(
  t1 = 110,
  t2 = 60,
  t0 = 5,
  insd1 = 0.1,
  insd2 = insd1,
  d1 = 0.25,
  d2 = d1,
  lambda1 = 0.09,
  lambda2 = 0.07,
  k1 = 1,
  k2 = k1,
  lambda0 = 1.74,
  z = 2,
  s = 0.55,
  len = 1,
  duration = 1
)
```

Arguments

t1	temperature of heat carrier (water) inside the supplying pipe, [$°C$]. Type: assert_double.
t2	temperature of heat carrier (water) inside the returning pipe, [$°C$]. Type: assert_double.
t0	temperature of environment, [$°C$]. For underground pipe this is the temperature of subsoil. Type: assert_double.
insd1	thickness of the insulator which covers the supplying pipe, [m]. Type: assert_double.
insd2	thickness of the insulator which covers the returning pipe, [m]. Type: assert_double.
d1	outside diameter of supplying pipe, [m]. Type: assert_double.
d2	outside diameter of returning pipe, [m]. Type: assert_double.
lambda1	thermal conductivity of insulator which covers the supplying pipe [$W/m/°C$]. Type: assert_double.
lambda2	thermal conductivity of insulator which covers the returning pipe [$W/m/°C$]. Type: assert_double.
k1	technical condition factor for insulator of supplying pipe, []. Type: assert_double.
k2	technical condition factor for insulator of returning pipe, []. Type: assert_double.

lambda0	thermal conductivity of environment, [*W/m/°C*]. For underground pipe this is the thermal conductivity of subsoil. Type: assert_double.
z	underground laying depth of supplying pipe, [*m*]. Type: assert_double.
s	distance between supplying and returning pipes, [*m*]. Type: assert_double.
len	length of supplying pipe, [*m*]. Type: assert_double.
duration	duration of heat loss, [*hour*]. Type: assert_double.

Details

Details on using k1 and k2 are the same as for m278hlcha.

Value

Normative heat loss of supplying underground cylindrical pipe during duration, [*kcal*]. If len of pipe is 1 *m* (meter) as well as duration is set to 1 *h* (hour) (default values) then the return value is also the *specific heat loss power*, [*kcal/m/h*] and so comparable with those prescribed by Minenergo Order 325. Type: assert_double.

See Also

Other Minenergo: m278hlair(), m278hlcha(), m278insdata, m278inshcm(), m278soildata, m325beta(), m325nhl(), m325nhldata, m325testbench

Examples

```
library(pipenostics)

m278hlund()
# [1] 102.6226
```

---

m278insdata — *Minenergo-278. Thermal conductivity terms of pipe insulation materials*

Description

Data represent values of terms (intercept and factor) for calculating thermal conductivity of pipe insulation as a linear function of temperature of heat carrier (water). Those values are set for different insulation materials in Appendix 5.3 of Minenergo Method 278 as norms.

Usage

```
m278insdata
```

Format

A data frame with 39 rows and 4 variables:

id Number of insulation material table 5.1 of Appendix 5.3 in Minenergo Method 278. Type: `assert_integerish`.

material Designation of insulation material more or less similar to those in table 5.1 of Appendix 5.3 in Minenergo Method 278. Type: `assert_character`.

lambda Value for intercept, [*mW/m/°C*]. Type: `assert_integer`.

k Value for factor. Type: `assert_integer`.

Details

Usually the data is not used directly. Instead use function `m278inshcm`.

Source

https://docs.cntd.ru/document/1200035568

See Also

Other Minenergo: `m278hlair()`, `m278hlcha()`, `m278hlund()`, `m278inshcm()`, `m278soildata`, `m325beta()`, `m325nhl()`, `m325nhldata`, `m325testbench`

`m278inshcm` *Minenergo-278. Thermal conductivity of pipe insulation materials*

Description

Get normative values of thermal conductivity of pipe insulation materials affirmed by Minenergo Method 278 as a function of temperature of heat carrier (water).

Usage

```
m278inshcm(temperature = 110, material = "aerocrete")
```

Arguments

`temperature`	temperature of heat carrier (water) inside the pipe, [°*C*]. Type: `assert_double`.
`material`	designation of insulation material as it stated in `m278insdata`, Type: `assert_subset`.

Value

Thermal conductivity of insulation materials at given set of temperatures, [*W/m/°C*], [*W/m/K*]. Type: `assert_double`.

See Also

Other Minenergo: m278hlair(), m278hlcha(), m278hlund(), m278insdata, m278soildata, m325beta(), m325nhl(), m325nhldata, m325testbench

Examples

```
 library(pipenostics)

# Averaged thermal conductivity of pipe insulation at 110 °C
print(m278insdata)
mean(m278inshcm(110, m278insdata[["material"]]))
# [1] 0.09033974  # [\emph{W/m/°C}]
```

---

m278soildata *Minenergo-278. Thermal conductivity of subsoil surrounding pipe*

Description

Data represent normative values of thermal conductivity of subsoils which can surround pipes according to Table 5.3 of Appendix 5.3 in Minenergo Method 278.

Usage

```
m278soildata
```

Format

A data frame with 15 rows and 3 variables:

subsoil Geological name of subsoil. Type: assert_character.

state The degree of water penetration to the subsoil. Type: assert_character.

lambda Value of thermal conductivity of subsoil regarding water penetration, [*W/m/°C*]. Type: assert_double.

Source

https://docs.cntd.ru/document/1200035568

See Also

Other Minenergo: m278hlair(), m278hlcha(), m278hlund(), m278insdata, m278inshcm(), m325beta(), m325nhl(), m325nhldata, m325testbench

`m325beta` *Minenergo-325. Local heat loss coefficient*

Description

Calculate β - *local heat loss coefficient* according to rule *11.3.3* of Minenergo Order 325. *Local heat loss coefficient* is used to increase normative heat loss of pipe by taking into account heat loss of fittings (shut-off valves, compensators and supports). This coefficient is applied mostly as a factor during the summation of heat losses of pipes in pipeline leveraging formula 14 of Minenergo Order 325.

Usage

```
m325beta(laying = "channel", d = 700)
```

Arguments

`laying`	type of pipe laying depicting the position of pipe in space: • `air`, • `channel`, • `room`, • `tunnel`, • `underground`. Type: `assert_subset`.
`d`	internal diameter of pipe, [*mm*]. Type: `assert_double`.

Value

Two possible values of β: `1.2` or `1.15` depending on pipe laying and its diameter. Type: `assert_double`.

See Also

Other Minenergo: `m278hlair()`, `m278hlcha()`, `m278hlund()`, `m278insdata`, `m278inshcm()`, `m278soildata`, `m325nhl()`, `m325nhldata`, `m325testbench`

Examples

```
 library(pipenostics)

norms <- within(m325nhldata, {
  beta <- m325beta(laying, as.double(diameter))
})
unique(norms$beta)
# [1] 1.15 1.20
```

`m325nhl` *Minenergo-325. Normative heat loss of pipe*

Description

Calculate normative heat loss of pipe that is legally affirmed by Minenergo Order 325.

Usage

```
m325nhl(
  year = 1986,
  laying = "underground",
  exp5k = TRUE,
  insulation = 0,
  d = 700,
  temperature = 110,
  len = 1,
  duration = 1,
  beta = FALSE,
  extra = 2
)
```

Arguments

`year`	year when the pipe is put in operation after laying or total overhaul. Type: `assert_integerish`
`laying`	type of pipe laying depicting the position of pipe in space: • `air`, • `channel`, • `room`, • `tunnel`, • `underground`. Type: `assert_subset`.
`exp5k`	pipe regime flag: is pipe operated more that 5000 hours per year? Type: `assert_logical`.
`insulation`	insulation that covers the exterior of pipe: `0` no insulation `1` foamed polyurethane or analogue `2` polymer concrete Type: `assert_integer` and `assert_subset`.
`d`	internal diameter of pipe, [*mm*]. Type: `assert_double`.
`temperature`	temperature of heat carrier (water) inside the pipe, [$^{\circ}C$]. Type: `assert_double`.
`len`	length of pipe, [*m*]. Type: `assert_double`.
`duration`	duration of heat loss, [*hour*]. Type: `assert_double`.
`beta`	should they consider additional heat loss of fittings? Type: `assert_logical`.
`extra`	number of points used for temperature extrapolation: `2`, `3`, or `4`. Type: `assert_choice`.

Details

Temperature extrapolation and pipe diameter interpolation are leveraged for better accuracy. Both are linear as it dictated by Minenergo Order 325. Nevertheless, one could control the extrapolation behavior by `extra` argument: use lower values of `extra` for soft curvature near extrapolation edges, and higher values for more physically reasoned behavior in far regions of extrapolation.

Value

Normative heat loss of cylindrical pipe during `duration`, [*kcal*]. If `len` of pipe is 1 *m* (meter) as well as `duration` is set to 1 *h* (hour) (default values) then the return value is also the *specific heat loss power*, [*kcal/m/h*], prescribed by Minenergo Order 325. Type: `assert_double`.

See Also

Other Minenergo: `m278hlair()`, `m278hlcha()`, `m278hlund()`, `m278insdata`, `m278inshcm()`, `m278soildata`, `m325beta()`, `m325nhldata`, `m325testbench`

Examples

```
library(pipenostics)

## Consider a 1-meter length pipe with
pipe_diameter <-  700.0  # [mm]
pipe_dating   <- 1980
pipe_laying   <- "underground"


## Linear extrapolation adopted in Minenergo's Order 325 using last two points:
operation_temperature <- seq(0, 270, 10)

qs <- m325nhl(
  year = pipe_dating, laying = pipe_laying, d = pipe_diameter,
  temperature = operation_temperature
)  # [kcal/m/h]

plot(
    operation_temperature,
    qs,
    type = "b",
    main = "Minenergo's Order 325. Normative heat loss of pipe",
    sub = sprintf(
      "%s pipe of diameter %i [mm] laid in %i",
       pipe_laying, pipe_diameter, pipe_dating
    ),
    xlab = "Temperature, [°C]",
    ylab = "Specific heat loss power, [kcal/m/h]"
  )


## Consider heat loss due fittings:
operation_temperature <- 65  # [°C]
```

```
fittings_qs <- m325nhl(
  year = pipe_dating, laying = pipe_laying, d = pipe_diameter,
  temperature = operation_temperature, beta = c(FALSE, TRUE)
)  # [kcal/m/h]

print(fittings_qs); stopifnot(all(round(fittings_qs ,1)  == c(272.0, 312.8)))

# [1] 272.0 312.8  # [kcal/m/h]



## Calculate heat flux:
operation_temperature <- c(65, 105)  # [°C]

qs <- m325nhl(
  year = pipe_dating, laying = pipe_laying, d = pipe_diameter,
  temperature = operation_temperature
)  # [kcal/m/h]
print(qs)

# [1] 272.00 321.75  # [kcal/m/h]

pipe_diameter <- pipe_diameter * 1e-3          # [m]
factor        <- 2.701283                      # [kcal/h/W]

flux <- qs/factor/pipe_diameter -> a  # heat flux, [W/m^2]
print(flux)

# [1] 143.8470 170.1572  # [W/m^2]

## The above line is equivalent to:

flux <- flux_loss(qs, pipe_diameter) -> b

stopifnot(all.equal(a, b, tolerance = 5e-6))
```

`m325nhldata` *Minenergo-325. Normative heat loss data*

Description

Data represent values of specific heat loss power officially accepted by Minenergo Order 325 as norms. Those values are maximums which are legally affirmed to contribute to normative heat loss $Q_N HL$ of district heating systems with water as a heat carrier.

Usage

```
m325nhldata
```

Format

A data frame with 17328 rows and 8 variables:

source Identifier of data source: identifiers suited with glob *t?p?* mean appropriate *table ?.?* in Minenergo Order 325; identifier *sgc* means that values are additionally postulated (see *Details*). Type: `assert_character`.

epoch Year depicting the epoch when the pipe is put in operation after laying or total overhaul. Type: `assert_integer`.

laying Type of pipe laying depicting the position of pipe in space. Only five types of pipe laying are considered:

- `air`,
- `channel`,
- `room`,
- `tunnel`,
- `underground`.

Type: `assert_character`.

exp5k Logical indicator for pipe regime: if `TRUE` pipe is operated more that `5000` hours per year. Type: `assert_logical`.

insulation Identifier of insulation that covers the exterior of pipe:

`0` no insulation

`1` foamed polyurethane or analogue

`2` polymer concrete

Type: `assert_integerish`.

diameter Nominal internal diameter of pipe, [*mm*]. Type: `assert_double`.

temperature Operational temperature of pipe, [°*C*]. Type: `assert_double`.

loss Normative value of specific heat loss power equal to heat flux output by 1 meter length steel pipe during an hour, [*kcal/m/hour*]. Type: `assert_double`.

Details

Data is organized as a full factorial design, whereas for some factorial combinations Minenergo Order 325 does not provide values. For that cases values are postulated by practical reasons in Siberian cities and marked with source label *sgc*.

Usually the data is not used directly. Instead use function `m325nhl`.

Source

`https://docs.cntd.ru/document/902148459`

See Also

Other Minenergo: `m278hlair()`, `m278hlcha()`, `m278hlund()`, `m278insdata`, `m278inshcm()`, `m278soildata`, `m325beta()`, `m325nhl()`, `m325testbench`

`m325testbench` *Minenergo-325. Test bench of district heating network*

Description

Data describes a virtual test bench of branched district heating network by exposing parameters associated with Minenergo Order 325. They treat data as a snapshot of network state and use it primarily for static thermal-hydraulic computations and topology effects.

Usage

```
m325testbench
```

Format

A data frame with 22 rows (number of nodes and incoming edges) and 15 variables:

sender An identifier of node which heat carrier flows out. Type: any type that can be painlessly coerced to character by `as.character`.

acceptor An identifier of node which heat carrier flows in. According to topology of test bench considered this identifier should be unique for every row. Type: any type that can be painlessly coerced to character by `as.character`.

temperature Snapshot of thermal-hydraulic regime state: temperature of heat carrier (water) sensor-measured on terminal acceptor node, [$^{\circ}C$]. Type: `assert_double`. `NA`s are introduced for nodes without temperature sensor.

pressure Snapshot of thermal-hydraulic regime state: sensor-measured absolute pressure of heat carrier (water) inside the pipe (i.e. acceptor's incoming edge), [*MPa*]. Type: `assert_double`. `NA`s are introduced for nodes without pressure sensor.

flow_rate Snapshot of thermal-hydraulic regime state: sensor-measured amount of heat carrier (water) on terminal node that is transferred by pipe (i.e. acceptor's incoming edge) during a period, [*ton/hour*]. Type: `assert_double`. `NA`s are introduced for nodes without flow rate sensor.

d internal diameter of pipe (i.e.diameter of acceptor's incoming edge), [*m*]. Type: `assert_double`.

len pipe length (i.e. length of acceptor's incoming edge), [*m*]. Type: `assert_double`.

year year when the pipe (i.e. acceptor's incoming edge) is put in operation after laying or total overhaul. Type: `assert_integerish`.

insulation identifier of insulation that covers the exterior of pipe (i.e. acceptor's incoming edge):

- `0` no insulation
- `1` foamed polyurethane or analogue
- `2` polymer concrete

Type: `assert_integerish`.

laying type of pipe laying depicting the position of pipe in space. Only five types of pipe laying are considered:

- air,
- channel,
- room,
- tunnel,
- underground.

Type: assert_character.

beta logical indicator: should they consider additional heat loss of fittings located on this pipe (i.e. acceptor's incoming edge)? Type: assert_logical.

exp5k logical indicator for regime of pipe (i.e. acceptor's incoming edge): if TRUE pipe is operated more that 5000 hours per year. Type: assert_logical.

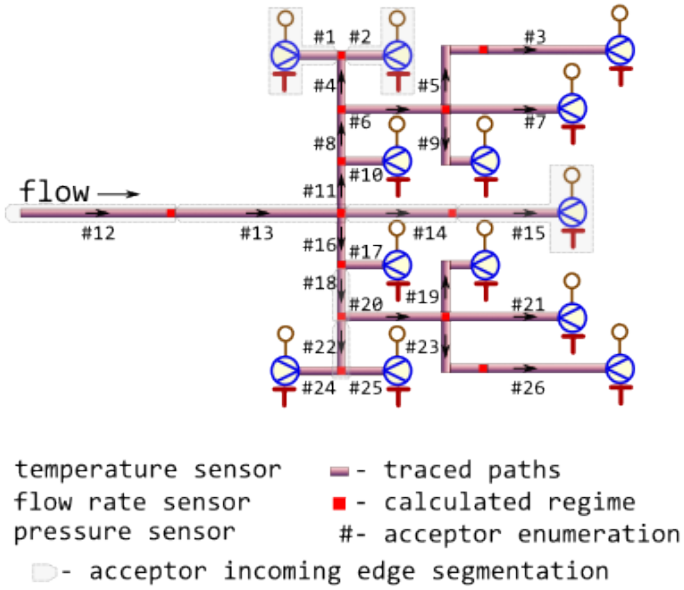
roughness roughness of internal wall of pipe (i.e. acceptor's incoming edge), [m]. Type: assert_double.

inlet elevation of pipe inlet, [m]. Type: assert_double.

outlet elevation of pipe outlet, [m]. Type: assert_double.

Details

The test bench has the next configuration:



As it may be seen from the figure there is a particularity in topology of the provided directed graph: each node has only single ancestor. Hence one of isomorphic representation of such directed graph is a data.frame in which each row describes a node along with its incoming edge and each column contains an attribute value for that node or an attribute value for its incoming edge.

Since they deal with incoming edges and hence nodes are all flow acceptors the natural enumeration of nodes is by acceptor id.

Note that to leverage igraph functionality for plotting there is a zero sender of flow.

See Also

Other Minenergo: m278hlair(), m278hlcha(), m278hlund(), m278insdata, m278inshcm(), m278soildata, m325beta(), m325nhl(), m325nhldata

Examples

```
 library(pipenostics)

# Do not hesitate to use `data.table` and `igraph` for larger chunks of network.

# Check for declared topology isomorphism:
stopifnot(
  all(!duplicated(m325testbench$acceptor))
)

# Do all terminal nodes have sensor-measured regime parameters?:
terminal_nodes <- subset(m325testbench, !(acceptor %in% sender))
stopifnot(
  all(!is.na(subset(terminal_nodes, select = c(temperature, pressure, flow_rate))))
)
```

---

m325tracebw *Minenergo-325. Massively trace backwards thermal-hydraulic regime for district heating network*

Description

Trace values of thermal-hydraulic regime (temperature, pressure, flow rate, and other) in the bunched pipeline against the flow direction using norms of heat loss values prescribed by Minenergo Order 325.

Algorithm also suits for partially measurable district heating network with massive data lack conditions, when there are no temperature and pressure sensor readings on the majority of terminal nodes.

Usage

```
m325tracebw(
  sender = 6,
  acceptor = 7,
  temperature = 70,
  pressure = pipenostics::mpa_kgf(6),
  flow_rate = 20,
  d = 100,
  len = 72.446,
  year = 1986,
  insulation = 0,
```

```
  laying = "tunnel",
  beta = FALSE,
  exp5k = TRUE,
  roughness = 0.001,
  inlet = 0.5,
  outlet = 1,
  method = "romeo",
  opinion = "median",
  verbose = TRUE,
  csv = FALSE,
  file = "m325tracebw.csv"
)
```

Arguments

sender	identifier of the node which heat carrier flows out. Type: any type that can be painlessly coerced to character by as.character.
acceptor	identifier of the node which heat carrier flows in. According to topology of test bench considered this identifier should be unique for every row. Type: any type that can be painlessly coerced to character by as.character.
temperature	Sensor-measured temperature of heat carrier (water) sensor-measured on the terminal acceptor node, [$°C$]. Use NA_float_s for (terminal) nodes without temperature sensor. Type: assert_double.
pressure	Sensor-measured absolute pressure of heat carrier (water) inside the pipe (i.e. acceptor's incoming edge), [MPa]. Type: assert_double.
flow_rate	Sensor-measured amount of heat carrier (water) on terminal node that is transferred by pipe (i.e. acceptor's incoming edge) during a period, [*ton/hour*]. Type: assert_double. Use NA_float_s for nodes without flow rate sensor.
d	internal diameter of pipe (i.e.diameter of acceptor's incoming edge), [mm]. Type: assert_double.
len	pipe length (i.e. length of acceptor's incoming edge), [m]. Type: assert_double.
year	year when the pipe (i.e. acceptor's incoming edge) is put in operation after laying or total overhaul. Type: assert_integerish.
insulation	identifier of insulation that covers the exterior of pipe (i.e. acceptor's incoming edge): 0 no insulation 1 foamed polyurethane or analogue 2 polymer concrete Type: assert_subset.
laying	type of pipe laying depicting the position of pipe in space. Only five types of pipe laying are considered: • air, • channel, • room,

- tunnel,
- underground.

Type: assert_subset.

beta — logical indicator: should they consider additional heat loss of fittings located on this pipe (i.e. acceptor's incoming edge)? Type: assert_logical.

exp5k — logical indicator for regime of pipe (i.e. acceptor's incoming edge): if TRUE pipe is operated more that 5000 hours per year. Type: assert_logical.

roughness — roughness of internal wall of pipe (i.e. acceptor's incoming edge), [*m*]. Type: assert_double.

inlet — elevation of pipe inlet, [*m*]. Type: assert_double.

outlet — elevation of pipe outlet, [*m*]. Type: assert_double.

method — method of determining *Darcy friction factor*:

- romeo
- vatankhan
- buzelli

Type: assert_choice. For more details see dropp.

opinion — method for aggregating values of regime parameters on each node for the next tracing step:

mean values of parameter are averaged before the next tracing step

median median of parameter values are used for the next tracing step

Type: assert_choice.

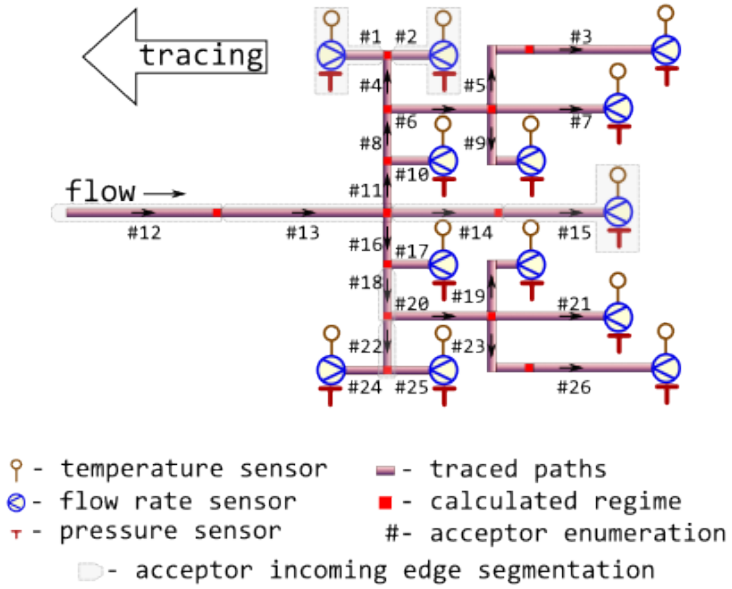
verbose — logical indicator: should they watch tracing process on console? Type: assert_flag.

csv — logical indicator: should they incrementally dump results to *csv*- file while tracing? Type: assert_flag.

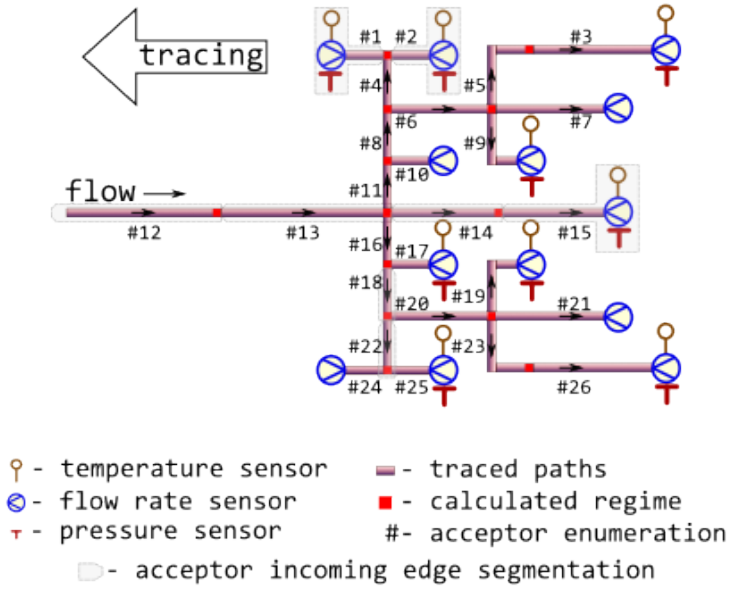
file — name of *csv*-file which they dump results to. Type: assert_character of length 1 that can be used safely to create a file and write to it.

Details

They consider the topology of district heating network represented by m325testbench:



The network may be partially sensor-equipped too:



In latter case no more than two nodes must be equipped with pressure and temperature sensors whereas for other nodes only flow rate sensors must be installed.

Tracing starts from sensor-equipped nodes and goes backwards, i.e against the flow direction.

Though some input arguments are natively vectorized their individual values all relate to common

part of district heating network, i.e. associated with common object. It is due to isomorphism between vector representation and directed graph of this network. For more details of isomorphic topology description see m325testbench.

Before tracing starts for the next node, previously calculated values of thermal-hydraulic parameters are aggregated by either averaging or by median. The latter seems more robust for avoiding strong influence of possible outliers which may come from actual heating transfer anomalies, erroneous sensor readings or wrong pipeline specifications.

Aggregation for values of flow rate at the node is always sum.

Value

data.frame containing results (detailed log) of tracing in narrow format:

node *Tracing job*. Identifier of the node which regime parameters is calculated for. Values in this vector are identical to those in argument acceptor. Type: assert_character.

tracing *Tracing job*. Identifiers of nodes from which regime parameters are traced for the given node. Identifier sensor is used when values of regime parameters for the node are sensor readings. Type: assert_character.

backward *Tracing job*. Identifier of tracing direction. It constantly equals to TRUE. Type: assert_logical.

aggregation *Tracing job*. Identifier of aggregation method: *span*, *median*, *mean*, or *identity*. Type: assert_character.

loss *Traced thermal hydraulic regime*. Normative specific heat loss power of adjacent pipe, [*kcal/m/h*]. Type: assert_double.

flux *Traced thermal hydraulic regime*. Normative heat flux of adjacent pipe, [*W/m^2*]. Type: assert_double.

Q *Traced thermal hydraulic regime*. Normative heat loss of adjacent pipe per day, [*kcal*]. Type: assert_character.

temperature *Traced thermal hydraulic regime*. Traced temperature of heat carrier (water) that is associated with the node, [°*C*]. Type: assert_double.

pressure *Traced thermal hydraulic regime*. Traced pressure of heat carrier (water) that is associated with the node, [*MPa*]. Type: assert_double.

flow_rate *Traced thermal hydraulic regime*. Traced flow rate of heat carrier (water) that is associated with the node, [*ton/hour*]. Type: assert_double.

job *Tracing job*. Value of tracing job counter. Type: assert_count.

Type: assert_data_frame.

See Also

Other Regime tracing: m325tracefw(), m325traceline(), tracebw(), tracefw(), traceline()

Examples

```
library(pipenostics)

## It is possible to run without specification of argument values:
```

```
m325tracebw()

## Consider isomorphic representation of District Heating Network graph:
DHN <- pipenostics::m325testbench
DHN$d <- 1e3*DHN$d  # convert [m] to [mm]

## When tracing large network graphs put screen log to file
output <- do.call("m325tracebw", c(as.list(DHN), verbose = TRUE))

## Distinct options for opinion aggregation lead to distinct traced
## temperature and pressure:

## * When aggregation is by mean:
output_mean <- do.call(
  "m325tracebw", c(as.list(DHN), verbose = FALSE, opinion = "mean")
)

## * When aggregation is by median:
output_median <- do.call(
  "m325tracebw", c(as.list(DHN), verbose = FALSE, opinion = "median")
)

## The differences between aggregations should be:
aggregation_differences <- c(delta_t = 0.03732, delta_p = 0.00139, delta_g = 0)
print(aggregation_differences)

## Check:
stopifnot(
  round(
    subset(
      output_mean,
      node == 13 & aggregation == "median",
      c("temperature", "pressure", "flow_rate")
    ) - subset(
      output_median,
      node == 13 & aggregation == "median",
      c("temperature", "pressure", "flow_rate")
    ),
    5
    # difference between aggregation options
  ) == aggregation_differences
)

## It is possible to process partially measurable District Heating Network:

## * Simulate lack of temperature and pressure sensors:
DHN[c(7, 10, 21, 24), c("temperature", "pressure")] <- NA_real_

## Trace thermal-hydraulic regime
output <- do.call("m325tracebw", c(as.list(DHN)))
print(output)
```

`m325tracefw` *Minenergo-325. Massively trace forwards thermal-hydraulic regime for district heating network*

Description

Trace values of thermal-hydraulic regime (temperature, pressure, flow rate, and other) in the bunched pipeline along the flow direction using norms of heat loss values prescribed by Minenergo Order 325.

Usage

```
m325tracefw(
  sender = c(0, 1),
  acceptor = c(1, 2),
  temperature = c(70, NA_real_),
  pressure = c(pipenostics::mpa_kgf(6), NA_real_),
  flow_rate = c(20, NA_real_),
  d = rep_len(100, 2),
  len = rep_len(72.446, 2),
  year = rep_len(1986, 2),
  insulation = rep_len(0, 2),
  laying = rep_len("tunnel", 2),
  beta = rep_len(FALSE, 2),
  exp5k = rep_len(TRUE, 2),
  roughness = rep_len(0.001, 2),
  inlet = c(0.5, 1),
  outlet = c(1, 1),
  elev_tol = 0.1,
  method = "romeo",
  verbose = TRUE,
  csv = FALSE,
  file = "m325tracefw.csv",
  use_cluster = FALSE
)
```

Arguments

`sender`	identifier of the node which heat carrier flows out. Type: any type that can be painlessly coerced to character by `as.character`.
`acceptor`	identifier of the node which heat carrier flows in. According to topology of test bench considered this identifier should be unique for every row. Type: any type that can be painlessly coerced to character by `as.character`.
`temperature`	Sensor-measured temperature of heat carrier (water) sensor-measured on the root node, [$°C$]. Use `NA_float_`s for nodes without temperature sensor. Type: `assert_double`.

`pressure` Sensor-measured absolute pressure of heat carrier (water) inside the pipe on the root node, [*MPa*]. Use `NA_float_s` for nodes without pressure sensor. Type: `assert_double`.

`flow_rate` Sensor-measured amount of heat carrier (water) on root node that is transferred by pipe during a period, [*ton/hour*]. Type: `assert_double`. Use `NA_float_s` for nodes without flow rate sensor.

`d` internal diameter of pipe (i.e.diameter of acceptor's incoming edge), [*mm*]. Type: `assert_double`.

`len` pipe length (i.e. length of acceptor's incoming edge), [*m*]. Type: `assert_double`.

`year` year when the pipe (i.e. acceptor's incoming edge) is put in operation after laying or total overhaul. Type: `assert_integerish`.

`insulation` identifier of insulation that covers the exterior of pipe (i.e. acceptor's incoming edge):

`0` no insulation

`1` foamed polyurethane or analogue

`2` polymer concrete

Type: `assert_subset`.

`laying` type of pipe laying depicting the position of pipe in space. Only five types of pipe laying are considered:

- `air`,
- `channel`,
- `room`,
- `tunnel`,
- `underground`.

Type: `assert_subset`.

`beta` logical indicator: should they consider additional heat loss of fittings located on this pipe (i.e. acceptor's incoming edge)? Type: `assert_logical`.

`exp5k` logical indicator for regime of pipe (i.e. acceptor's incoming edge): if `TRUE` pipe is operated more that `5000` hours per year. Type: `assert_logical`.

`roughness` roughness of internal wall of pipe (i.e. acceptor's incoming edge), [*m*]. Type: `assert_double`.

`inlet` elevation of pipe inlet, [*m*]. Type: `assert_double`.

`outlet` elevation of pipe outlet, [*m*]. Type: `assert_double`.

`elev_tol` maximum allowed discrepancy between adjacent outlet and inlet elevations of two subsequent pipes in the traced path, [*m*]. Type: `assert_number`.

`method` method of determining *Darcy friction factor*:

- `romeo`
- `vatankhan`
- `buzelli`

Type: `assert_choice`. For more details see `dropp`.

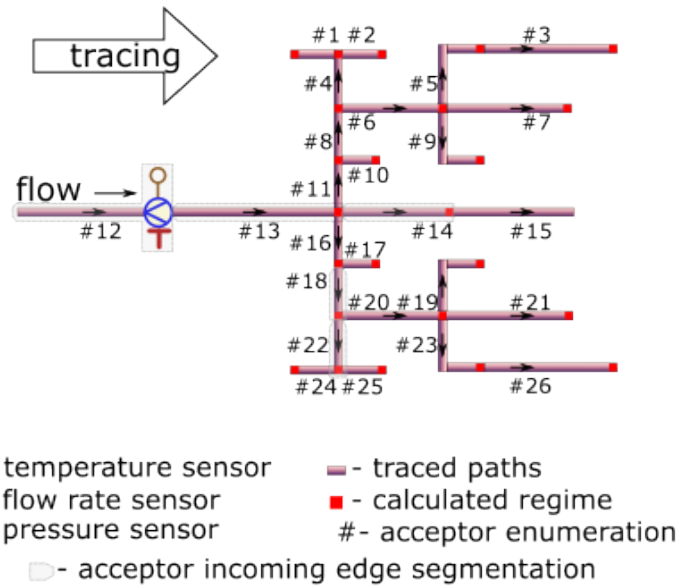
`verbose` logical indicator: should they watch tracing process on console? Type: `assert_flag`.

csv	logical indicator: should they incrementally dump results to *csv*- file while tracing? Type: assert_flag.
file	name of *csv*-file which they dump results to. Type: assert_character of length 1 that can be used safely to create a file and write to it.
use_cluster	utilize functionality of parallel processing on multi-core CPU. Type: assert_flag.

Details

The calculated (values of) regime may be considered as representation of district heating process in conditions of hypothetically perfect technical state of pipe walls and insulation.

They consider the topology of district heating network represented by m325testbench:



Tracing starts from sensor-equipped root node and goes forward, i.e along the flow direction. Function m325traceline serves under the hood for tracing identified linear segments from root node to every terminal node. Hence they only need root node to be equipped with sensors. Sensors at other nodes are redundant in forward tracing, since the tracing algorithm by no means consider them for tracing.

Moreover in the forward tracing algorithm they assume the flow of heat carrier is distributed proportionally to the cross-sectional area of the outgoing pipeline. Actually, a lot of reasons may cause significant deviations from this assumption. As a result, the sequence of paired backward/forward tracing may be divergent for regime parameters.

Though some input arguments are natively vectorized their individual values all relate to common part of district heating network, i.e. associated with common object. It is due to isomorphism between vector representation and directed graph of this network. For more details of isomorphic topology description see m325testbench.

They are welcome to couple the algorithm with functionality of data.table.

Value

data.frame containing results (detailed log) of tracing in narrow format:

node *Tracing job*. Identifier of the node which regime parameters is calculated for. Values in this vector are identical to those in argument acceptor. Type: assert_character.

tracing *Tracing job*. Identifiers of nodes from which regime parameters are traced for the given node. Identifier sensor is used when values of regime parameters for the node are sensor readings. Type: assert_character.

backward *Tracing job*. Identifier of tracing direction. It constantly equals to FALSE. Type: assert_logical.

aggregation *Tracing job*. Identifier of the aggregation method associated with traced values. For forward tracing the only option is identity. Type: assert_character.

temperature *Traced thermal hydraulic regime*. Traced temperature of heat carrier (water) that is associated with the node, [$^{\circ}C$]. Type: assert_double.

pressure *Traced thermal hydraulic regime*. Traced pressure of heat carrier (water) that is associated with the node, [*MPa*]. Type: assert_double.

flow_rate *Traced thermal hydraulic regime*. Traced flow rate of heat carrier (water) that is associated with the node, [*ton/hour*]. Type: assert_double.

job *Tracing job*. Value of tracing job counter. For forward tracing value of job counts the number of traced paths from root node. Type: assert_count.

Type: assert_data_frame.

See Also

Other Regime tracing: m325tracebw(), m325traceline(), tracebw(), tracefw(), traceline()

Examples

```
library(pipenostics)

# Minimum two nodes should be in district heating network graph:
m325tracefw(verbose = FALSE)

# Consider isomorphic representation of District Heating Network graph:
DHN <- pipenostics::m325testbench

# * avoid using numeric identifiers for nodes:
DHN$sender   <- sprintf("N%02i", DHN$sender)
DHN$acceptor <- sprintf("N%02i", DHN$acceptor)

# * alter units:
DHN$d <- 1e3 * DHN$d  # convert [m] to [mm]

# Perform backward tracing to get regime on root node:
bw_report <- do.call("m325tracebw", c(as.list(DHN), verbose = FALSE))

# Put the traced values to the root node of test bench:
root_node_idx <- 12
root_node <- sprintf("N%02i", root_node_idx)
```

```
regime_param  <- c("temperature", "pressure", "flow_rate")
DHN[root_node_idx, regime_param] <-
  subset(bw_report,
         node == root_node & aggregation == "median",
         regime_param)
rm(root_node, root_node_idx)

# Trace the test bench forward for the first time:
fw_report <- do.call("m325tracefw",
                     c(as.list(DHN), verbose = FALSE, elev_tol = .5))

# Let's compare traced regime at terminal nodes back to test bench:
report <- subset(
  rbind(bw_report, fw_report),
  node %in% subset(DHN, !(acceptor %in% sender))$acceptor &
    aggregation == "identity"
)

regime_delta <- colMeans(
  subset(report, backward, regime_param) -
    subset(report, !backward, regime_param)
)
print(regime_delta)

stopifnot(sqrt(regime_delta %*% regime_delta) < 0.5)
```

`m325traceline` *Minenergo-325. Trace thermal-hydraulic regime for linear segment of district heating network*

Description

Trace values of thermal-hydraulic regime (temperature, pressure, flow_rate, and other) along the adjacent linear segments of pipeline using norms of heat loss values prescribed by Minenergo Order 325.

Usage

```
m325traceline(
  temperature = 130,
  pressure = mpa_kgf(6),
  flow_rate = 250,
  g = 0,
  d = 700,
  len = c(600, 530, 300, 350),
  year = 1986,
  insulation = 0,
  laying = "underground",
```

```
  beta = FALSE,
  exp5k = TRUE,
  roughness = 0.006,
  inlet = 0,
  outlet = 0,
  elev_tol = 0.1,
  method = "romeo",
  forward = TRUE,
  absg = TRUE
)
```

Arguments

temperature	*Traced thermal hydraulic regime*. Sensor-measured temperature of heat carrier (water) inside the pipe sensor-measured at the inlet (forward tracing) or at the outlet (backward tracing) of path, [$°C$]. Type: assert_number.
pressure	*Traced thermal hydraulic regime*. Sensor-measured absolute pressure of heat carrier (water) sensor-measured at the inlet (forward tracing) or at the outlet (backward tracing) of path, [*MPa*]. Type: assert_number.
flow_rate	*Traced thermal hydraulic regime*. Amount of heat carrier (water) sensor-measured at the inlet (forward tracing) or at the outlet (backward tracing) of path, [*ton/hour*]. Type: assert_number.
g	amount of heat carrier discharge to network for each pipe segment in the tracing path enumerated along the direction of flow. If flag absg is TRUE then they treat argument g as absolute value in [*ton/hour*], otherwise they do as percentage of flow_rate in the pipe segment. Type: assert_double.
d	internal diameters of subsequent pipes in tracing path that are enumerated along the direction of flow, [*mm*]. Type: assert_double.
len	length of subsequent pipes in tracing path that are enumerated along the direction of flow, [*m*]. Type: assert_double.
year	year when pipe is put in operation after laying or total overhaul for each pipe in tracing path enumerated along the direction of flow. Type: assert_integerish.
insulation	insulation that covers the exterior of pipe: 0 no insulation 1 foamed polyurethane or analogue 2 polymer concrete for each pipe in tracing path enumerated along the direction of flow. Type: assert_numeric and assert_subset.
laying	type of pipe laying depicting the position of pipe in space: • air • channel • room • tunnel • underground

for each pipe in tracing path enumerated along the direction of flow. Type: assert_character and assert_subset.

beta — logical indicator: should they consider additional heat loss of fittings? Logical value for each pipe in tracing path enumerated along the direction of flow. Type: assert_logical.

exp5k — logical indicator for regime of pipe: is pipe operated more that 5000 hours per year? Logical value for each pipe in tracing path enumerated along the direction of flow. Type: assert_logical.

roughness — roughness of internal wall for each pipe in tracing path enumerated along the direction of flow, [*m*]. Type: assert_double.

inlet — elevation of pipe inlet for each pipe in tracing path enumerated along the direction of flow, [*m*]. Type: assert_double.

outlet — elevation of pipe outlet for each pipe in tracing path enumerated along the direction of flow, [*m*]. Type: assert_double.

elev_tol — maximum allowed discrepancy between adjacent outlet and inlet elevations of two subsequent pipes in the traced path, [*m*]. Type: assert_number.

method — method of determining *Darcy friction factor*

- romeo
- vatankhan
- buzelli

Type: assert_choice. For more details see dropp.

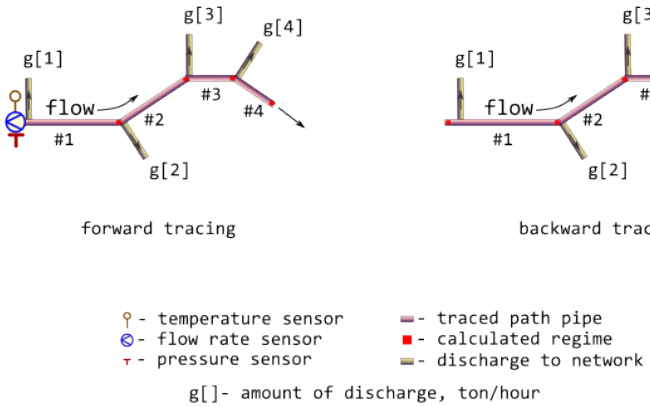
forward — tracing direction flag: is it a forward direction of tracing? If FALSE the backward tracing is performed. Type: assert_flag.

absg — Whether argument g (amount of heat carrier discharge to network) is an absolute value in [*ton/hour*] (TRUE) or is it a percentage of flow rate in the pipe segment (FALSE)? Type: assert_flag.

Details

The calculated (values of) regime may be considered as representation of district heating process in conditions of hypothetically perfect technical state of pipe walls and insulation.

They consider only simple tracing paths which do not contain rings and any kind of parallelization. At the same time bidirectional (forward and backward) tracing is possible in accordance with sensor position. They also may consider discharges to network at the inlet of each pipeline segment as an approximation of actual forks of flows. Relevant illustration of adopted assumptions for 4-segment tracing path is depicted on the next figure.



They make additional check for consistency of `inlet` and `outlet` values for subsequent pipe segments. Discrepancy of appropriate elevations cannot be more than `elev_tol`.

Since inner diameter of the pipe is used as input, the the thickness of the pipe wall additionally considered in heat flux calculations. Pipe wall thickness is derived from pipe diameter using GOST 30732 specifications.

Value

`list` containing results (detailed log) of tracing for each pipe in tracing path enumerated along the direction of flow:

`temperature` *Traced thermal hydraulic regime*. Traced temperature of heat carrier (water), [°*C*]. Type: `assert_double`.

`pressure` *Traced thermal hydraulic regime*. Traced pressure of heat carrier (water) for each pipe in tracing path enumerated along the direction of flow, [*MPa*]. Type: `assert_double`.

`flow_rate` *Traced thermal hydraulic regime*. Traced flow rate of heat carrier (water) for each pipe in tracing path enumerated along the direction of flow, [*ton/hour*]. Type: `assert_double`.

`loss` *Traced thermal hydraulic regime*. Normative specific heat loss power for each pipe in tracing path enumerated along the direction of flow, [*kcal/m/h*]. Type: `assert_double`.

`flux` *Traced thermal hydraulic regime*. Normative heat flux for each pipe in tracing path enumerated along the direction of flow, [*W/m^2*]. Type: `assert_double`.

`Q` *Traced thermal hydraulic regime*. Normative heat loss for each pipe in tracing path enumerated along the direction of flow per day, [*kcal*]. Type: `assert_double`.

Type: `assert_list`.

See Also

Other Regime tracing: `m325tracebw()`, `m325tracefw()`, `tracebw()`, `tracefw()`, `traceline()`

Examples

```
library(pipenostics)

# Consider 4-segment tracing path depicted in ?m325regtrace help page.
```

```
# First, let sensor readings for forward tracing:
t_fw <- 130  # [°C]
p_fw <- mpa_kgf(6)*all.equal(.588399, mpa_kgf(6))  # [MPa]
g_fw <- 250  # [ton/hour]

# Let discharges to network for each pipeline segment are somehow determined as
discharges <- seq(0, 30, 10)  # [ton/hour]

# Then the calculated regime (red squares) for forward tracing is
regime_fw <- m325traceline(t_fw, p_fw, g_fw, discharges, forward = TRUE)
print(regime_fw)

# $temperature
# [1] 129.1799 128.4269 127.9628 127.3367
#
# $pressure
# [1] 0.5878607 0.5874226 0.5872143 0.5870330
#
# $flow_rate
# [1] 250 240 220 190
#
# $loss
# [1] 348.0000 347.1389 346.3483 345.8610
#
# $flux
# [1] 181.9600 181.5097 181.0963 180.8415
#
# $Q
# [1] 5011200 4415607 2493707 2905232


# Next consider values of traced regime as sensor readings for backward tracing:
t_bw <- 127.3367  # [°C]
p_bw <- .5870330  # [MPa]
g_bw <- 190  # [ton/hour]

# Then the calculated regime (red squares) for backward tracing is
regime_bw <- m325traceline(t_bw, p_bw, g_bw, discharges, forward = FALSE)
print(regime_bw)

# $temperature
# [1] 129.9953 129.1769 128.4254 127.9619
#
# $pressure
# [1] 0.5883998 0.5878611 0.5874228 0.5872144
#
# $flow_rate
# [1] 250 250 240 220
#
# $loss
# [1] 347.1358 346.3467 345.8599 345.2035
#
# $flux
```

```
# [1] 181.5081 181.0955 180.8410 180.4978
#
# $Q
# [1] 4998755 4405529 2490192 2899710

# Let compare sensor readings with backward tracing results:
tracing <- with(regime_bw, {
  lambda <- function(val, constraint)
    c(val, constraint, constraint - val,
      abs(constraint - val)*100/constraint)
  first <- 1
  structure(
    rbind(
      lambda(temperature[first], t_fw),
      lambda(pressure[first],    p_fw),
      lambda(flow_rate[first], g_fw)
    ),
    dimnames = list(
      c("temperature", "pressure", "flow_rate"),
      c("sensor.value", "traced.value", "abs.discr", "rel.discr")
    )
  )
})
print(tracing)

# sensor.value traced.value     abs.discr    rel.discr
# temperature  129.9952943   130.000000  4.705723e-03 0.0036197868
# pressure       0.5883998     0.588399 -8.215938e-07 0.0001396321
# flow_rate    250.0000000   250.000000  0.000000e+00 0.0000000000
```

`mepof` *Probability of failure of the corroded pipe within maximum entropy*

Description

Calculate *probability of failure* (POF) of the corroded pipe taking into account its actual level of defectiveness and exploiting Monte-Carlo simulation within Principle of maximum entropy.

Consistent estimate of POF for pipeline systems plays a critical role in optimizing their operation. To prevent pipeline failures due to actively growing defects it is necessary to be able to assess the pipeline system failure operation probability during a certain period, taking into account its actual level of defectiveness. The pipeline limit state comes when the burst pressure, considered as a random variable, reaches an unacceptable level, or when the defect depth, also a random variable, exceeds the predetermined limit value.

That is why in the method they consider two possible failures for a single pipeline cross section with the on-surface and longitudinally oriented defect of *metal-loss* type:

rupture a decrease of value of failure pressure down to the operating pressure.

leak increase of corrosion depth (defect) up to the specified ultimate permissible fraction of pipe wall thickness.

Since up to now no methods existed which would give absolutely correct POF assessments they suggest simple fiddling with random values of affecting factors without deeping into intrinsic mechanisms of corrossion. For this purpose they choose classical Monte-Carlo simulation within the Principle of maximum entropy. The latter allows to avoid doubtful and excessive preferences and detalization when choosing probability distribution models for failure factors and for *inline inspection* measurements.

Usage

```
mepof(
  depth = seq(0, 10, length.out = 100),
  l = seq(40, 50, length.out = 100),
  d = rep.int(762, 100),
  wth = rep.int(10, 100),
  strength = rep.int(358.5274, 100),
  pressure = rep.int(0.588, 100),
  temperature = rep.int(150, 100),
  rar = function(n) stats::runif(n, 0.01, 0.3)/365,
  ral = function(n) stats::runif(n, 0.01, 0.3)/365,
  days = 0,
  k = 0.8,
  method = "b31g",
  n = 1e+06
)
```

Arguments

`depth`	maximum depth of the corroded area measured during *inline inspection*, [*mm*]. Type: `assert_double`.
`l`	maximum longitudinal length of corroded area measured during *inline inspection*, [*mm*]. Type: `assert_double`.
`d`	nominal outside diameter of pipe, [*mm*]. Type: `assert_double`.
`wth`	nominal wall thickness of pipe, [*mm*]. Type: `assert_double`.
`strength`	one of the next characteristics of steel strength, [*MPa*]: • specified minimum yield of stress (*SMYS*) for use with `b31gpf` and `b31gmodpf`. • ultimate tensile strength (*UTS*) or specified minimum tensile strength (*SMTS*) for use with other failure pressure codes (`dnvpf`, `pcorrcpf`, `shell92pf`). Type: `assert_double`.
`pressure`	absolute pressure of substance (i.e. heat carrier) inside the pipe measured near defect position, [*MPa*]. In most cases this is a nominal operating pressure. Type: `assert_double`.
`temperature`	temperature of substance (i.e. heat carrier) inside the pipe measured near defect position, [°*C*]. In case of district heating network this is usually a calculated value according to actual or normative thermal-hydraulic regime. Type: `assert_double`.

`rar` — random number generator for simulating of distribution of radial corrosion rate in pipe wall, [*mm/day*]. The only argument `n` of the function should be the number of observations to generate. Type: `assert_function`.

`ral` — random number generator for simulating of distribution of longitudinal corrosion rate in pipe wall, [*mm/day*]. The only argument `n` of the function should be the number of observations to generate. Type: `assert_function`.

`days` — number of days that have passed after or preceded the *inline inspection*, []. Negative values are for retrospective assumptions whereas positives are for failure prognosis. Type: `assert_int`.

`k` — alarm threshold for leakage failure. It usually `0.6`, `0.7`, or `0.8`, []. If set to `1` no alarm before failure occurs. Type: `assert_number`.

`method` — method for calculating failure pressure:

- *b31g* - using `b31gpf`.
- *b31gmod* - using `b31gmodpf`.
- *dnv* - using `dnvpf`.
- *pcorrc* - using `pcorrcpf`.
- *shell92* - using `shell92pf`.

Type: `assert_choice`.

`n` — number of observations to generate for Monte-Carlo simulations, Type: `assert_count`.

Details

Since for all influence factors they can more or less assume range limits, the *uniform distribution* gets the maximum entropy in this context (see JCGM 101:2008). That is why parameters of corrosion defects measured during the *inline inspection* as well as regime parameters and engineering characteristics of pipe segment - all they are simulated by `runif`.

`runif`-limits for depth of corrosion defect are associated with precision of commonly applied measurement instruments. For traditionally exploited ultrasonic control those limits are well-known and can reach up to 10 % of pipe wall thickness. Whereas uncertainty of defect longitudinal length may be more than enough constrained with 5 %.

Recommendations for choosing stochastic characteristics of pipe engineering factors (i.e. crossection diameter, wall thickness and material strength) are taken from aggregated review of *Timashev et al.* but gently transformed for compatibility with Principle of maximum entropy, i.e. `runif`.

Uncertainties of regime parameters in stohastic models are set minimized by regarding only precision of metering devices which commonly applied in district heating networks. For temperature it is about 2 °C.

Since the rate of corrosion processes in the pipe wall is a consequence of physical and chemical processes occurring at the atomic scale, it depends on a large number of environmental factors differently and ambiguously. That is why various deterministic and stochastic models can be potentially involved in POF assessment. For that purpose radial and longitudinal corrosion rate can be independently formulated as random value generation functions. They only admit that change in depth and length of corrosion defects in time is close to linear for the generated value of corrosion rate.

Value

Probability of pipe failure for each corroded area measured during *inline inspection*. Type: assert_double. If NAs returned use another method for calculating failure pressure.

References

1. S. Timashev and A. Bushinskaya, *Diagnostics and Reliability of Pipeline Systems*, Topics in Safety, Risk, Reliability and Quality 30, **DOI 10.1007/978-3-319-25307-7**.
2. BIPM. Guides in Metrology (GUM). JCGM 101:2008. Evaluation of measurement data – **Supplement 1** to the *Guide to the expression of uncertainty in measurement* – Propagation of distributions using a *Monte Carlo* method.

Examples

```
 library(pipenostics)


# Let's consider a pipe in district heating network with
diameter           <- 762         # [mm]
wall_thickness     <-  10         # [mm]
UTS                <- 434.3697    # [MPa]

# which transfers heat-carrier (water) at
operating_pressure <-   0.588399  # [MPa].
temperature        <-  95         # [°C]

# During inline inspection four corroded areas (defects) are detected with:
depth  <- c(2.45,  7.86,   7.93,   8.15)  # [mm]

# whereas the length of all defects is not greater 200 mm:
length <- rep(200, 4)  # [mm]

# Corrosion rates in radial and in longitudinal directions are not well-known and
# may vary in range .01 - .30 mm/year:
rar = function(n) stats::runif(n, .01, .30) / 365
ral = function(n) stats::runif(n, .01, .30) / 365

# Then POFs related to each corroded area are near:
pof <- mepof(depth, length, rep(diameter, 4), rep(wall_thickness, 4),
             rep(UTS, 4), rep(operating_pressure, 4), rep(temperature, 4),
             rar, ral, method = "dnv")
print(pof)
# 0.000000 0.252510 0.368275 0.771595

# So, the POF of pipe is near
print(max(pof))
# 0.771595

# The value of POF changes in time. So, in a year after inline inspection of
# the pipe we can get something near
pof <- mepof(depth, length, rep(diameter, 4), rep(wall_thickness, 4),
```

```
            rep(UTS, 4), rep(operating_pressure, 4), rep(temperature, 4),
            rar, ral, method = "dnv", days = 365)
print(pof)
# 0.000000 0.525539 0.648359 0.929099

# for entire pipe we get something near:
print(max(pof))
# 0.929099

# Two years ago before inline inspection the pipe state was rather good:
pof <- mepof(depth, length, rep(diameter, 4), rep(wall_thickness, 4),
            rep(UTS, 4), rep(operating_pressure, 4), rep(temperature, 4),
            rar, ral, method = "dnv", days = -2 * 365)

print(pof)
# 0.000000 0.040780 0.072923 0.271751

# for entire pipe we get something near:
print(max(pof))
# 0.271751
```

`meteos` *Get list of weather stations (meteos)*

Description

Get a list of weather stations located primarily in the central and northern parts of Eurasia. For each weather station, the following information is provided: an integer station ID, geographic coordinates, altitude, and the mean annual ground temperature averaged over depth.

Usage

```
meteos()
```

Value

list of weather stations (meteos) with the next fields:

`station_id` Weather station unique identifier. Type: `assert_integer`.

`name` Human-readable name of weather station. Type: `assert_character`.

`lat` Geographical position of wether station. Latitude, [*DD*]. Type: `assert_double`.

`lon` Geographical position of wether station. Longitude, [*DD*]. Type: `assert_double`.

`alt` Altitude - position of weather station above sea level, [m]. Type: `assert_double`.

`avg` Mean annual ground temperature averaged over depth, [°*C*]. Type: `assert_double`.

Type: `assert_data_frame`.

References

Climate Change Investigation Laboratory. Description of the array of daily data on soil temperature at depths up to 320 centimeters by meteorological stations of the *Russian Federation*.

See Also

`mgtdhid` to get hourly ground temperature values at different depths measured at the listed weather stations.

Other utils: `geoarea()`, `mgtdhid()`, `wth_d()`

Examples

```
library(pipenostics)
head(meteos())
```

`mgtdhid` *Get ground temperature*

Description

Get the undisturbed (median) value of ground temperature at different depths at a specified time leveraging *Modified Ground Temperature Double Harmonic Model* (*MGTDH*-model).

Usage

```
mgtdhid(id, tau = 1440L, depth = 2.4)

mgtdhidt(tau, id = 28434L, depth = 2.4)

mgtdhgeo(lat, lon, tau = 1440L, depth = 2.4, use_cluster = FALSE)

mgtdhgeot(tau, lat = 57, lon = 57, depth = 2.4)
```

Arguments

`id`	weather station unique identifier. Only identifiers from `meteos` dataset are accepted. Type: `assert_integer`. For `mgtdhidt` acceptable length is 1.
`tau`	time point for which it is necessary to obtain the value of the soil temperature; it can be specified as an integer, representing the number of hours that have passed since the beginning of the year, or as a value of `POSIXct` type. Type: `assert_count`, or `assert_posixct`. For `mgtdhid` acceptable length is 1.
`depth`	depth at which the ground temperature is calculated, [*m*]. Type: `assert_number`.
`lat`	latitude of the geographical location where the value of soil temperature needs to be determined, [*DD*]. Type: `assert_double`. For `mgtdhgeot` acceptable length is 1.

`lon`	longitude of the geographical location where the value of soil temperature needs to be determined, [*DD*]. Type: `assert_double`. For `mgtdhgeot` acceptable length is `1`.
`use_cluster`	utilize functionality of parallel processing on multi-core CPU. Type: `assert_flag`.

Details

The *MGTDH*-model is a modified solution of the thermal conductivity equation for soil and can be expressed by the formula

$$t\left(\tau, d\right) = \beta e^{r_1} \cdot A_1 \cos(2\pi\omega\tau + r_1 - P_1) + \beta r_2^{A_2 \cdot d} \cos(4\pi\omega\tau + r_2 - P_2)$$

where

$t\left(\tau, d\right)$ undisturbed (median) ground temperature [$^{\circ}C$] at specified depth d [*m*], and time τ [*hour*].

τ time point (`tau`) calculated in hours since the beginning of the year, [*hour*].

d depth (`depth`) at which the ground temperature should be calculated, [*m*].

$\beta = -1$ shift constant, [].

$r_1(d) = -1000d\sqrt{\frac{\pi\omega}{\alpha_s D}}$, $r_2(d) = r_1(d)\sqrt{2}$ temperature diffusivity factors, [].

$\omega = \frac{1}{8760}$ rate of rotation of the *Earth*, expressed with an accuracy equal to the inverse of an hour, [*1/hour*].

α_s soil diffusivity, [*mm^2/s*].

$D = 86400$ constant that represents the number of seconds in one day, [*s/day*].

A_1, A_2 harmonic temperature amplitudes, [$^{\circ}C$].

P_1, P_2 phase shifts, depending on the geographical location, [].

Soil diffusivity, α_s, harmonic temperature amplitudes, A_1, A_2, and phase shifts P_1, P_2 are geographically dependant parameters which values were established for each weather station listed in `meteos`-dataset.

For the convenience of using the *MGTDH*-model, several interface functions have been provided. Each function generates a vector of type `assert_double` as an output.

The `mgtdhid` and `mgtdhidt` functions are used to obtain ground temperature data from specific meteorological stations.

The functions `mgtdhgeo` and `mgtdhgeot` provide ground temperatures at any geographical location, but note that their usage is primarily limited to the Northern Asian part of *Eurasia*, as most meteorological stations and parameters for the *MGTDH*-model are established there. Ground temperature at the specified location is obtained by linear interpolation using barycentric coordinates formed in the system of the three nearest meteorological stations.

Value

Undisturbed (median) ground temperature value calculated with the *MGTDH*-model, specifically for the location of the user-specified meteorological station, at specified depth, and time, [$^{\circ}C$]. Type: `assert_double`.

References

Lu Xing & Jeffrey D. Spitler (2017) *Prediction of undisturbed ground temperature using analytical and numerical modeling. Part I: Model development and experimental validation*. Science and Technology for the Built Environment, 23:5, 787-808, doi:10.1080/23744731.2016.1258371.

See Also

`geodist` and `geoarea` for calculating geographical metrics.

Other utils: `geoarea()`, `meteos()`, `wth_d()`

Examples

```
# Let consider the next geographical positions:
lat <- c(s28434 = 56.65, s28418 = 56.47, s23711 = 62.70, ControlPoint = 57)
lon <- c(s28434 = 57.78, s28418 = 53.73, s23711 = 56.20, ControlPoint = 57)

# * ground temperatures at first three locations on 02 March 2023 at depth 3 m:
mgtdhgeo(head(lat, 3), head(lon, 3), tau = as.POSIXct("2023-03-02"), depth = 3)

# * it is the same as obtaining ground temperatures from weather stations:
mgtdhid(id = c(28434L, 28418L, 23711L), tau = as.POSIXct("2023-03-02"), depth = 3)

# * undisturbed ground temperature plot at Control Point:
days <- as.POSIXct("2023-01-01") + 3600*24*(seq.int(1, 365) - 1)
plot(
  days,
  mgtdhgeot(days, lat[["ControlPoint"]], lon[["ControlPoint"]]),
  type = "l",
  ylab = "Temperature, °C"
)
```

`mm_inch` *Inches to mm*

Description

Convert length measured in inches to millimeters (mm)

Usage

```
mm_inch(x)
```

Arguments

`x`	length measured in *inches*, [*inch*]. Type: `assert_double`.

Value

length in *millimeters*, [*mm*]. Type: assert_double.

See Also

inch_mm for converting *mm* to *inches*

Other units: c_k(), f_k(), inch_mm(), k_c(), kgf_mpa(), loss_flux(), mpa_kgf(), mpa_psi(), psi_mpa()

Examples

```
library(pipenostics)

mm_inch(c(0.03937008, 1))
# [1]  1.0 25.4  # [mm]
```

---

mpa_kgf *Kilogram-force per square cm to megapascals*

Description

Convert pressure (stress) measured in kilogram-force per square cm (kgf/cm^2) to megapascals (MPa)

Usage

```
mpa_kgf(x)
```

Arguments

x	pressure (stress) measured in *kilogram-force per square cm*, [*kgf/cm^2*]. Type: assert_double.

Value

pressure (stress) in *megapascals*, [*MPa*]. Type: assert_double.

See Also

kgf_mpa for converting *megapascals* to *kilogram-force per square cm*

Other units: c_k(), f_k(), inch_mm(), k_c(), kgf_mpa(), loss_flux(), mm_inch(), mpa_psi(), psi_mpa()

Examples

```
library(pipenostics)

mpa_kgf(c(10.1971619998, 1))
# [1] 1.0000000 0.0980665  # [MPa]
```

`mpa_psi` *Pounds per square inch to megapascals*

Description

Convert pressure (stress) measured in pounds per square inch (PSI) to megapascals (MPa)

Usage

```
mpa_psi(x)
```

Arguments

`x`	pressure (stress) measured in *pounds per square inch* (*PSI*). Type: `assert_double`.

Value

pressure (stress) in *megapascals* (*MPa*). Type: `assert_double`.

See Also

`psi_mpa` for converting *megapascals* to *pounds per square inch*

Other units: `c_k()`, `f_k()`, `inch_mm()`, `k_c()`, `kgf_mpa()`, `loss_flux()`, `mm_inch()`, `mpa_kgf()`, `psi_mpa()`

Examples

```
library(pipenostics)

mpa_psi(c(145.03773800721814, 1))
# [1] 1.000000000 0.006894757 # [MPa]
```

pcorrcpf *PCORRC. Failure pressure of the corroded pipe*

Description

Calculate failure pressure of the corroded pipe according to *PCORRC* model.

PCORRC methodology was developed on the basis of studying the mechanism of destruction of pipes, material of which has improved or high fracture toughness, and on the high-precision modeling of the finite element pipe models performed at the *Battelle Institute*. According to field test results of a large number of actual pipe segments, the destruction mechanism for defective pipeline segment depends on the pipe material fracture toughness. These tests also showed that only pipes made out of steel with improved or high fracture toughness fail a result of plastic fracture. In determining the *Folias* factor the effect of increased stress concentration and steel hardening in the plastic deformation zone at the start of the defect failure process was taken into account.

This code should be applied only to

- a single cross section of the pipeline containing a longitudinally oriented, flat bottom surface defect of corrosion/erosion type;
- pipelines, which operate at temperatures exceeding the temperature of pipe material ductile–brittle transition, and for pipematerial with the impact energy of Charpy 61 [*J*] and above.

Usage

```
pcorrcpf(d, wth, uts, depth, l)
```

Arguments

d	nominal outside diameter of pipe, [*mm*]. Type: assert_double.
wth	nominal wall thickness of pipe, [*mm*]. Type: assert_double.
uts	ultimate tensile strength (*UTS*) or specified minimum tensile strength (*SMTS*) as a characteristic of steel strength, [MPa]. Type: assert_double.
depth	measured maximum depth of the corroded area, [*mm*]. Type: assert_double.
l	measured maximum longitudinal length of corroded area, [*mm*]. Type: assert_double.

Value

Estimated failure pressure of the corroded pipe, [MPa]. Type: assert_double.

References

1. S. Timashev and A. Bushinskaya, *Diagnostics and Reliability of Pipeline Systems*, Topics in Safety, Risk, Reliability and Quality 30, **DOI 10.1007/978-3-319-25307-7**
2. A.C.Reddy, *Safety Failure Criteria of Fluorocarbon Plastic Pipes for Dry Chlorine Transport using Finite Element Analysis* Materials today: proceedings, Vol. **4**(8), 2017, pp. **7498-7506**. **DOI 10.1016/j.matpr.2017.07.081**

See Also

Other fail pressure functions: b31gpf, b31gmodpf, dnvpf, shell92pf

Examples

```
library(pipenostics)

d     <- c(812.8, 219.0)  # [mm]
wth   <- c( 19.1,  14.5)  # [mm]
uts   <- c(530.9, 455.1)   # [N/mm^2]
l     <- c(203.2, 200.0)  # [mm]
depth <- c( 13.4,   9.0)   # [mm]

pcorrcpf(d, wth, uts, depth, l)
# [1] 16.35449 33.01288
```

---

psi_mpa *Megapascals to pounds per square inch*

Description

Convert pressure (stress) measured in megapascals (MPa) to pounds per square inch (PSI)

Usage

```
psi_mpa(x)
```

Arguments

x	pressure (stress) measured in *megapascals*. [*MPa*]. Type: assert_double.

Value

pressure (stress) in *pounds per square inch*, [*PSI*]. Type: assert_double.

See Also

mpa_psi for converting *pounds per square inch* to *megapascals*

Other units: c_k(), f_k(), inch_mm(), k_c(), kgf_mpa(), loss_flux(), mm_inch(), mpa_kgf(), mpa_psi()

Examples

```
library(pipenostics)

psi_mpa(c(6.89475728e-3, 1))
# [1] 1.0000 145.0377 # [PSI]
```

re_u *Estimate Reynolds number*

Description

Estimate *Reynolds number* for fluid flow in a cylindrical pipe.

Usage

```
re_u(d, mu, u, rho)

re_v(d, mu, v, rho)

re_m(d, mu, m)
```

Arguments

d	internal diameter of pipe, [*m*]. Type: assert_double.
mu	dynamic viscosity of fluid in pipe, [*kg/m/s*]. Type: assert_double.
u	mean velocity of fluid in pipe, [*m/s*]. Type: assert_double.
rho	mass density of fluid in pipe, [*kg/m^3*]. Type: assert_double.
v	volumetric flow rate of fluid in pipe, [*m^3/s*]. Type: assert_double.
m	mass flow rate of fluid in pipe, [*kg/s*]. Type: assert_double.

Details

The calculation of *Reynolds number* is bounded by physically reasonable limits of fluid properties found in domain specificity of the package.

Value

Reynolds number - a dimensionless quantity that reveals the ratio between inertial and viscous forces in the fluid, []. Type: assert_double.

See Also

Other Fluid properties: fric_buzelli(), fric_romeo(), fric_vatankhan()

Examples

```
library(pipenostics)

# Reynolds numbers for typical district heating water flows at temperature
# near 25 C in a set of pipes with different sizes:
range(re_u(seq(.25, 1, 0.05), .89, 1, 1000))
# [1]  280.8989 1123.5955
```

shell92pf *Shell92. Failure pressure of the corroded pipe*

Description

Calculate failure pressure of the corroded pipe according to *Shell92* code.

This code should be applied only to

- single cross section of the pipeline containing a longitudinally oriented, flat bottom surface defect of corrosion/erosion type;
- defects which depth is less than 85 % of pipe wall thickness.

The estimation is valid for single isolated metal loss defects of the corrosion/erosion type and when only internal pressure loading is considered.

As in the case of dnvpf, the defect is approximated by a rectangular form.

Usage

```
shell92pf(d, wth, uts, depth, l)
```

Arguments

d	nominal outside diameter of pipe, [*mm*]. Type: assert_double.
wth	nominal wall thickness of pipe, [*mm*]. Type: assert_double.
uts	ultimate tensile strength (*UTS*) or specified minimum tensile strength (*SMTS*) as a characteristic of steel strength, [*MPa*]. Type: assert_double.
depth	measured maximum depth of the corroded area, [*mm*]. Type: assert_double.
l	measured maximum longitudinal length of corroded area, [*mm*]. Type: assert_double.

Details

Numeric NAs may appear in case prescribed conditions of use are offended.

Value

Estimated failure pressure of the corroded pipe, [*MPa*]. Type: assert_double.

References

Timashev and A. Bushinskaya, *Diagnostics and Reliability of Pipeline Systems*, Topics in Safety, Risk, Reliability and Quality 30, **DOI 10.1007/978-3-319-25307-7**

See Also

Other fail pressure functions: b31gpf, b31gmodpf, dnvpf, pcorrcpf

Examples

```
 library(pipenostics)

d     = c(812.8, 219.0)  # [mm]
wth   = c( 19.1,  14.5)  # [mm]
uts  = c(530.9, 455.1)   # [N/mm^2]
l     = c(203.2, 200.0)  # [mm]
depth = c( 13.4,   9.0)  # [mm]

shell92pf(d, wth, uts, depth, l)
# [1] 11.09262 25.27286
```

`strderate` *DNV-RP-F101. De-rate yield stress and tensile strength of pipe due to temperature*

Description

Temperature is highly influence on pipe material properties and especially on its strength. Since in API SPECIFICATION 5L values of *SMYS* or *UTS* are postulated at room conditions, in case of higher temperature magnitudes they should be corrected. For that purpose DNV-RP-F101 offers linear de-rating for *SMYS* or *SMYS* according to figure 2-3.

Usage

```
strderate(x, temperature = 24.3)
```

Arguments

`x`	specified minimum yield of stress (*SMYS*), or ultimate tensile strength (*UTS*), or specified minimum tensile strength (*SMTS*) as a characteristic of steel strength **at room temperature**, [*MPa*]. Type: `assert_double`.
`temperature`	temperature of pipe wall, [°*C*]. Type: `assert_double`.

Value

de-rated value of *x*, i.e. of appropriate pipe material property, [*MPa*] . Type: `assert_double`.

See Also

Other DNV-RP-F101 functions: `dnvpf()`

Examples

```
 library(pipenostics)

with(api5l3t, {
print(strderate(mpa_psi(smys), 53))
print(
  strderate(mpa_psi(uts),seq(0, 250, length.out = length(smys)))
)
})
# [1] 170.5689 205.0427 239.5165 287.7798 315.3588 356.7274 384.3064 411.8854 446.3592 480.8330
# [11] 549.7806
# [1] 310.2641 330.9483 413.6854 398.6854 404.3697 415.0540 439.5278 457.1068 460.8963 485.3701
# [11] 530.5282
```

`tracebw` *Massively trace backwards thermal-hydraulic regime for district heating network*

Description

Trace values of thermal-hydraulic regime (temperature, pressure, flow rate, and other) in the bunched pipeline against the flow direction using user-provided values of *specific heat loss power*.

Algorithm also suits for partially measurable district heating network with massive data lack conditions, when there are no temperature and pressure sensor readings on the majority of terminal nodes.

Usage

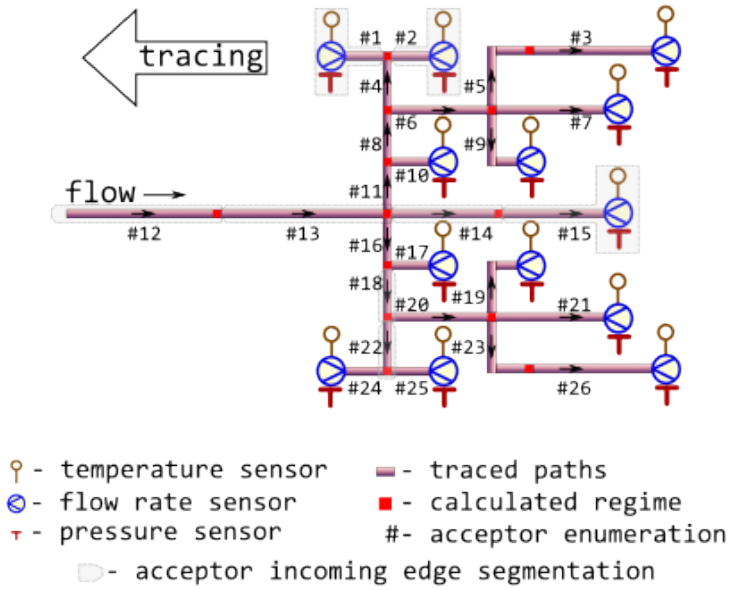
```
tracebw(
  sender = 6,
  acceptor = 7,
  temperature = 70,
  pressure = pipenostics::mpa_kgf(6),
  flow_rate = 20,
  d = 100,
  len = 72.446,
  loss = 78.4,
  roughness = 0.001,
  inlet = 0.5,
  outlet = 1,
  method = "romeo",
  opinion = "median",
  verbose = TRUE,
  csv = FALSE,
  file = "tracebw.csv"
)
```

Arguments

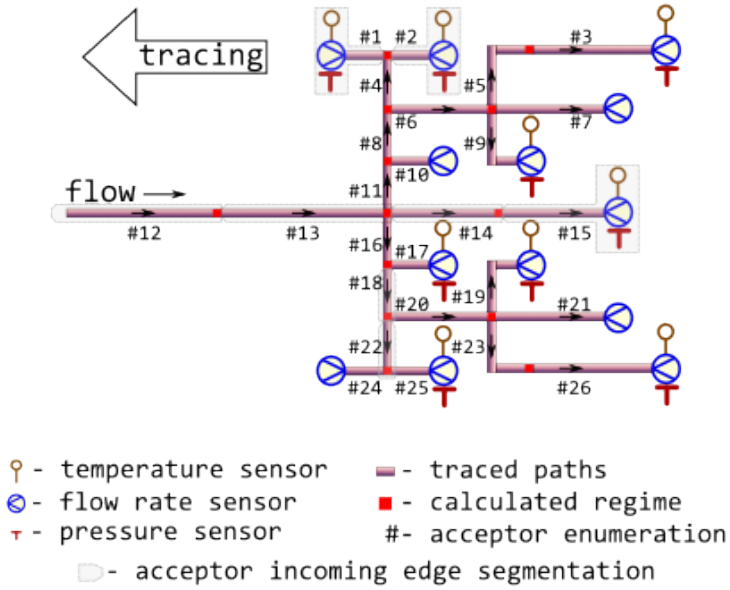
sender	identifier of the node which heat carrier flows out. Type: any type that can be painlessly coerced to character by as.character.
acceptor	identifier of the node which heat carrier flows in. According to topology of test bench considered this identifier should be unique for every row. Type: any type that can be painlessly coerced to character by as.character.
temperature	Sensor-measured temperature of heat carrier (water) sensor-measured on the terminal acceptor node, [$°C$]. Use NA_float_s for (terminal) nodes without temperature sensor. Type: assert_double.
pressure	Sensor-measured absolute pressure of heat carrier (water) inside the pipe (i.e. acceptor's incoming edge), [*MPa*]. Type: assert_double.
flow_rate	Sensor-measured amount of heat carrier (water) on terminal node that is transferred by pipe (i.e. acceptor's incoming edge) during a period, [*ton/hour*]. Type: assert_double. Use NA_float_s for nodes without flow rate sensor.
d	internal diameter of pipe (i.e.diameter of acceptor's incoming edge), [*mm*]. Type: assert_double.
len	pipe length (i.e. length of acceptor's incoming edge), [*m*]. Type: assert_double.
loss	user-provided value of *specific heat loss* power for each pipe, [*kcal/m/h*]. Values of the argument can be obtained experimentally, or taken from regulatory documents. Type: assert_double.
roughness	roughness of internal wall of pipe (i.e. acceptor's incoming edge), [*m*]. Type: assert_double.
inlet	elevation of pipe inlet, [*m*]. Type: assert_double.
outlet	elevation of pipe outlet, [*m*]. Type: assert_double.
method	method of determining *Darcy friction factor*: • romeo • vatankhan • buzelli Type: assert_choice. For more details see dropp.
opinion	method for aggregating values of regime parameters on each node for the next tracing step: mean values of parameter are averaged before the next tracing step median median of parameter values are used for the next tracing step Type: assert_choice.
verbose	logical indicator: should they watch tracing process on console? Type: assert_flag.
csv	logical indicator: should they incrementally dump results to *csv*- file while tracing? Type: assert_flag.
file	name of *csv*-file which they dump results to. Type: assert_character of length 1 that can be used safely to create a file and write to it.

Details

They consider the topology of district heating network represented by `m325testbench`:



The network may be partially sensor-equipped too:



In latter case no more than two nodes must be equipped with pressure and temperature sensors

whereas for other nodes only flow rate sensors must be installed.

Tracing starts from sensor-equipped nodes and goes backwards, i.e against the flow direction.

Though some input arguments are natively vectorized their individual values all relate to common part of district heating network, i.e. associated with common object. It is due to isomorphism between vector representation and directed graph of this network. For more details of isomorphic topology description see `m325testbench`.

Before tracing starts for the next node, previously calculated values of thermal-hydraulic parameters are aggregated by either averaging or by median. The latter seems more robust for avoiding strong influence of possible outliers which may come from actual heating transfer anomalies, erroneous sensor readings or wrong pipeline specifications.

Aggregation for values of flow rate at the node is always `sum`.

Value

`data.frame` containing results (detailed log) of tracing in narrow format:

`node` *Tracing job*. Identifier of the node which regime parameters is calculated for. Values in this vector are identical to those in argument `acceptor`. Type: `assert_character`.

`tracing` *Tracing job*. Identifiers of nodes from which regime parameters are traced for the given node. Identifier `sensor` is used when values of regime parameters for the node are sensor readings. Type: `assert_character`.

`backward` *Tracing job*. Identifier of tracing direction. It constantly equals to `TRUE`. Type: `assert_logical`.

`aggregation` *Tracing job*. Identifier of aggregation method: *span*, *median*, *mean*, or *identity*. Type: `assert_character`.

`loss` *Traced thermal hydraulic regime*. Normative specific heat loss power of adjacent pipe, [*kcal/m/h*]. Type: `assert_double`.

`flux` *Traced thermal hydraulic regime*. Normative heat flux of adjacent pipe, [*W/m^2*]. Type: `assert_double`.

`Q` *Traced thermal hydraulic regime*. Normative heat loss of adjacent pipe per day, [*kcal*]. Type: `assert_character`.

`temperature` *Traced thermal hydraulic regime*. Traced temperature of heat carrier (water) that is associated with the node, [°*C*]. Type: `assert_double`.

`pressure` *Traced thermal hydraulic regime*. Traced pressure of heat carrier (water) that is associated with the node, [*MPa*]. Type: `assert_double`.

`flow_rate` *Traced thermal hydraulic regime*. Traced flow rate of heat carrier (water) that is associated with the node, [*ton/hour*]. Type: `assert_double`.

`job` *Tracing job*. Value of tracing job counter. Type: `assert_count`.

Type: `assert_data_frame`.

See Also

Other Regime tracing: `m325tracebw()`, `m325tracefw()`, `m325traceline()`, `tracefw()`, `traceline()`

Examples

```
library(pipenostics)

# It is possible to run without specification of argument values:
m325tracebw()

# Consider isomorphic representation of District Heating Network graph:
DHN <- pipenostics::m325testbench

# * Adapt units:
DHN$d <- 1e3*DHN$d  # convert [m] to [mm]

# * Adapt node identifiers for ordering representation simplification:
DHN[["sender"]]   <- sprintf("N%02i", DHN[["sender"]])
DHN[["acceptor"]] <- sprintf("N%02i", DHN[["acceptor"]])

# * Provided actual values of specific heat loss power (say, field measurements) for each
#   pipe in DHN, [kcal/m/h]:
 actual_loss <- c(
               # acceptor:
      96.236,  #  1
      96.288,  #  2
      70.584,  #  3
     116.045,  #  4
      70.734,  #  5
      96.211,  #  6
      78.400,  #  7
     116.016,  #  8
      28.115,  #  9
      24.918,  # 10
     116.679,  # 11
       0.000,  # 12, may be unmeasured!
     153.134,  # 13
      96.733,  # 14
      96.600,  # 15
     116.667,  # 16
      24.960,  # 17
     115.923,  # 18
      28.166,  # 19
      96.123,  # 20
      77.824,  # 21
     115.946,  # 22
      70.690,  # 23
      96.184,  # 24
      96.236,  # 25
      70.540   # 26
 )

# * Remove inappropriate attributes of the graph:
DHN.1 <- DHN[, setdiff(colnames(DHN), c("year", "insulation", "laying", "beta", "exp5k"))]

# * Trace thermal-hydraulic regime for DHN:
```

```
tracebw_report <- do.call("tracebw", c(as.list(DHN.1), list(loss = actual_loss)))

# * If the actual values of specific heat loss power presented above are close
#   to those in Minenergo-325, then the results of regime tracing match the
#   normative procedure:
m325_report <- do.call("m325tracebw", DHN)

stopifnot(
   all.equal(tracebw_report$temperature, m325_report$temperature, tolerance = 1e-4),
   all.equal(tracebw_report$pressure   , m325_report$pressure   , tolerance = 1e-4),
   all.equal(tracebw_report$flow_rate  , m325_report$flow_rate  , tolerance = 1e-4)
  )
```

`tracefw` *Massively trace forwards thermal-hydraulic regime for district heating network*

Description

Trace values of thermal-hydraulic regime (temperature, pressure, flow rate, and other) in the bunched pipeline along the flow direction using user-provided values of *specific heat loss power*.

Usage

```
tracefw(
  sender = c(0, 1),
  acceptor = c(1, 2),
  temperature = c(70, NA_real_),
  pressure = c(pipenostics::mpa_kgf(6), NA_real_),
  flow_rate = c(20, NA_real_),
  d = rep_len(100, 2),
  len = rep_len(72.446, 2),
  loss = rep_len(78.4, 2),
  roughness = rep_len(0.001, 2),
  inlet = c(0.5, 1),
  outlet = c(1, 1),
  elev_tol = 0.1,
  method = "romeo",
  verbose = TRUE,
  csv = FALSE,
  file = "tracefw.csv",
  use_cluster = FALSE
)
```

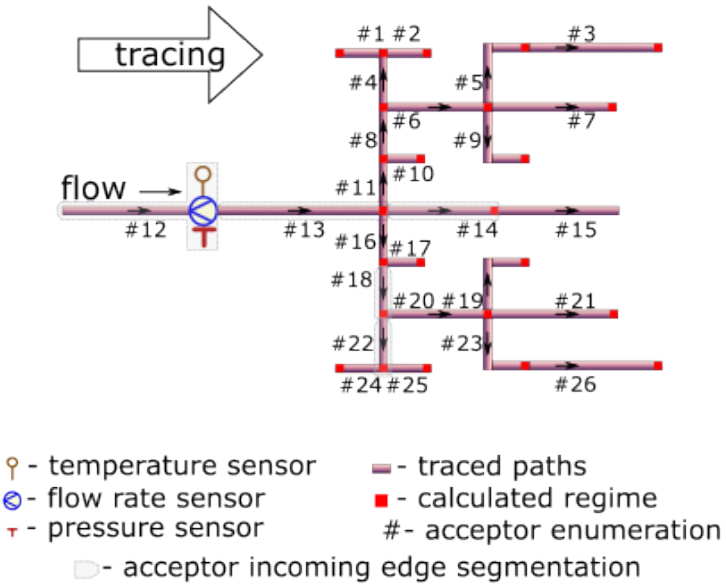
Arguments

`sender`	identifier of the node which heat carrier flows out. Type: any type that can be painlessly coerced to character by `as.character`.

acceptor	identifier of the node which heat carrier flows in. According to topology of test bench considered this identifier should be unique for every row. Type: any type that can be painlessly coerced to character by as.character.
temperature	Sensor-measured temperature of heat carrier (water) sensor-measured on the root node, [$°C$]. Use NA_float_s for nodes without temperature sensor. Type: assert_double.
pressure	Sensor-measured absolute pressure of heat carrier (water) inside the pipe on the root node, [*MPa*]. Use NA_float_s for nodes without pressure sensor. Type: assert_double.
flow_rate	Sensor-measured amount of heat carrier (water) on root node that is transferred by pipe during a period, [*ton/hour*]. Type: assert_double. Use NA_float_s for nodes without flow rate sensor.
d	internal diameter of pipe (i.e.diameter of acceptor's incoming edge), [*mm*]. Type: assert_double.
len	pipe length (i.e. length of acceptor's incoming edge), [*m*]. Type: assert_double.
loss	user-provided value of *specific heat loss* power for each pipe in tracing path, [*kcal/m/h*]. Values of the argument can be obtained experimentally, or taken from regulatory documents. Type: assert_double.
roughness	roughness of internal wall of pipe (i.e. acceptor's incoming edge), [*m*]. Type: assert_double.
inlet	elevation of pipe inlet, [*m*]. Type: assert_double.
outlet	elevation of pipe outlet, [*m*]. Type: assert_double.
elev_tol	maximum allowed discrepancy between adjacent outlet and inlet elevations of two subsequent pipes in the traced path, [*m*]. Type: assert_number.
method	method of determining *Darcy friction factor*: • romeo • vatankhan • buzelli Type: assert_choice. For more details see dropp.
verbose	logical indicator: should they watch tracing process on console? Type: assert_flag.
csv	logical indicator: should they incrementally dump results to *csv*- file while tracing? Type: assert_flag.
file	name of *csv*-file which they dump results to. Type: assert_character of length 1 that can be used safely to create a file and write to it.
use_cluster	utilize functionality of parallel processing on multi-core CPU. Type: assert_flag.

Details

They consider the topology of district heating network represented by m325testbench:



Tracing starts from sensor-equipped root node and goes forward, i.e along the flow direction. Function `traceline` serves under the hood for tracing identified linear segments from root node to every terminal node. Hence they only need root node to be equipped with sensors. Sensors at other nodes are redundant in forward tracing, since the tracing algorithm by no means consider them for tracing.

Moreover in the forward tracing algorithm they assume the flow of heat carrier is distributed proportionally to the cross-sectional area of the outgoing pipeline. Actually, a lot of reasons may cause significant deviations from this assumption. As a result, the sequence of paired backward/forward tracing may be divergent for regime parameters.

Though some input arguments are natively vectorized their individual values all relate to common part of district heating network, i.e. associated with common object. It is due to isomorphism between vector representation and directed graph of this network. For more details of isomorphic topology description see `m325testbench`.

They are welcome to couple the algorithm with functionality of data.table.

Value

`data.frame` containing results (detailed log) of tracing in narrow format:

`node` *Tracing job*. Identifier of the node which regime parameters is calculated for. Values in this vector are identical to those in argument `acceptor`. Type: `assert_character`.

`tracing` *Tracing job*. Identifiers of nodes from which regime parameters are traced for the given node. Identifier `sensor` is used when values of regime parameters for the node are sensor readings. Type: `assert_character`.

`backward` *Tracing job*. Identifier of tracing direction. It constantly equals to `FALSE`. Type: `assert_logical`.

`aggregation` *Tracing job*. Identifier of the aggregation method associated with traced values. For forward tracing the only option is `identity`. Type: `assert_character`.

`temperature` *Traced thermal hydraulic regime*. Traced temperature of heat carrier (water) that is associated with the node, [$°C$]. Type: `assert_double`.

`pressure` *Traced thermal hydraulic regime*. Traced pressure of heat carrier (water) that is associated with the node, [*MPa*]. Type: `assert_double`.

`flow_rate` *Traced thermal hydraulic regime*. Traced flow rate of heat carrier (water) that is associated with the node, [*ton/hour*]. Type: `assert_double`.

`job` *Tracing job*. Value of tracing job counter. For forward tracing value of `job` counts the number of traced paths from root node. Type: `assert_count`.

Type: `assert_data_frame`.

See Also

Other Regime tracing: `m325tracebw()`, `m325tracefw()`, `m325traceline()`, `tracebw()`, `traceline()`

Examples

```
library(pipenostics)

# Minimum two nodes should be in district heating network graph:
tracefw(verbose = FALSE)

# Consider isomorphic representation of District Heating Network graph:
DHN <- pipenostics::m325testbench

# * remove irrelevant parameters from the test bench
DHN[c("year", "insulation", "laying", "beta", "exp5k")] <- NULL
DHN[c("temperature", "pressure", "flow_rate")] <- NA_real_

# * avoid using numeric identifiers for nodes:
DHN$sender   <- sprintf("N%02i", DHN$sender)
DHN$acceptor <- sprintf("N%02i", DHN$acceptor)

# * alter units:
DHN$d <- 1e3 * DHN$d  # convert [m] to [mm]

# * provide current regime parameters for root node
root_node <- 12
DHN[root_node, "temperature"] <-  70.4942576978  # [°C]
DHN[root_node, "pressure"]    <-   0.6135602014  # [MPa]
DHN[root_node, "flow_rate"]   <- 274.0           # [ton/hour]

# * provide actual values of specific heat loss power, [kcal/m/h], for each
# segment N01 - N26. Since N12 is a root node, the specific heat loss
# power for this acceptor is set to 0 (or may be any other numeric value).
actual_loss <- c(
  96.8,  96.8,  71.2, 116.7, 71.3,  96.8, 78.5, 116.7, 28.6, 24.5,
 116.7,   0.0, 153.2,  96.8, 96.8, 116.7, 24.5, 116.7, 28.6, 96.8,
  78.5, 116.7,  71.3,  96.8, 96.8,  71.1
)
```

```
# Trace the test bench forward for the first time:
fw_report <- do.call(
  "tracefw", c(as.list(DHN), list(loss = actual_loss), verbose = FALSE, elev_tol = .5)
)
```

`traceline` *Trace thermal-hydraulic regime for linear segment of district heating network*

Description

Trace values of thermal-hydraulic regime (temperature, pressure, flow_rate, and other) along the adjacent linear segments of pipeline using user-provided values of *specific heat loss power*.

Usage

```
traceline(
  temperature = 130,
  pressure = mpa_kgf(6),
  flow_rate = 250,
  g = 0,
  d = 700,
  len = c(600, 530, 300, 350),
  loss = c(348, 347.1389, 346.3483, 345.861),
  roughness = 0.006,
  inlet = 0,
  outlet = 0,
  elev_tol = 0.1,
  method = "romeo",
  forward = TRUE,
  absg = TRUE
)
```

Arguments

`temperature`	*Traced thermal hydraulic regime*. Sensor-measured temperature of heat carrier (water) inside the pipe sensor-measured at the inlet (forward tracing) or at the outlet (backward tracing) of path, [$°C$]. Type: `assert_number`.
`pressure`	*Traced thermal hydraulic regime*. Sensor-measured absolute pressure of heat carrier (water) sensor-measured at the inlet (forward tracing) or at the outlet (backward tracing) of path, [*MPa*]. Type: `assert_number`.
`flow_rate`	*Traced thermal hydraulic regime*. Amount of heat carrier (water) sensor-measured at the inlet (forward tracing) or at the outlet (backward tracing) of path, [*ton/hour*]. Type: `assert_number`.

`g` amount of heat carrier discharge to network for each pipe segment in the tracing path enumerated along the direction of flow. If flag `absg` is `TRUE` then they treat argument g as absolute value in [*ton/hour*], otherwise they do as percentage of flow_rate in the pipe segment. Type: `assert_double`.

`d` internal diameters of subsequent pipes in tracing path that are enumerated along the direction of flow, [*mm*]. Type: `assert_double`.

`len` length of subsequent pipes in tracing path that are enumerated along the direction of flow, [*m*]. Type: `assert_double`.

`loss` user-provided value of *specific heat loss* power for each pipe in tracing path enumerated along the direction of flow, [*kcal/m/h*]. Values of the argument can be obtained experimentally, or taken from regulatory documents. Type: `assert_double`.

`roughness` roughness of internal wall for each pipe in tracing path enumerated along the direction of flow, [*m*]. Type: `assert_double`.

`inlet` elevation of pipe inlet for each pipe in tracing path enumerated along the direction of flow, [*m*]. Type: `assert_double`.

`outlet` elevation of pipe outlet for each pipe in tracing path enumerated along the direction of flow, [*m*]. Type: `assert_double`.

`elev_tol` maximum allowed discrepancy between adjacent outlet and inlet elevations of two subsequent pipes in the traced path, [*m*]. Type: `assert_number`.

`method` method of determining *Darcy friction factor*

- `romeo`
- `vatankhan`
- `buzelli`

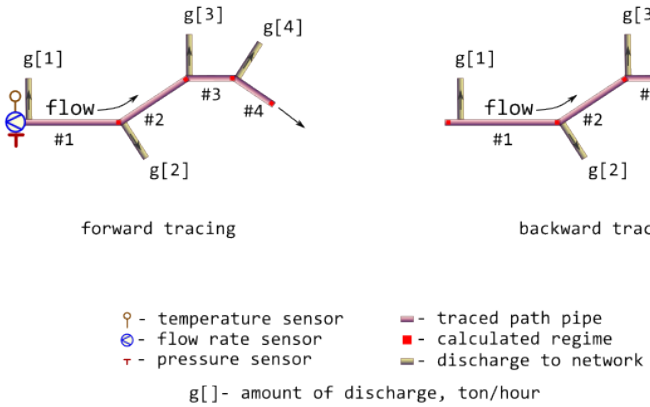
Type: `assert_choice`. For more details see `dropp`.

`forward` tracing direction flag: is it a forward direction of tracing? If `FALSE` the backward tracing is performed. Type: `assert_flag`.

`absg` Whether argument g (amount of heat carrier discharge to network) is an absolute value in [*ton/hour*] (`TRUE`) or is it a percentage of flow rate in the pipe segment (`FALSE`)? Type: `assert_flag`.

Details

They consider only simple tracing paths which do not contain rings and any kind of parallelization. At the same time bidirectional (forward and backward) tracing is possible in accordance with sensor position. They also may consider discharges to network at the inlet of each pipeline segment as an approximation of actual forks of flows. Relevant illustration of adopted assumptions for 4-segment tracing path is depicted on the next figure.



They make additional check for consistency of `inlet` and `outlet` values for subsequent pipe segments. Discrepancy of appropriate elevations cannot be more than `elev_tol`.

Since inner diameter of the pipe is used as input, the the thickness of the pipe wall additionally considered in heat flux calculations. Pipe wall thickness is derived from pipe diameter using GOST 30732 specifications.

Value

`list` containing results (detailed log) of tracing for each pipe in tracing path enumerated along the direction of flow:

`temperature` *Traced thermal hydraulic regime*. Traced temperature of heat carrier (water), [°*C*]. Type: `assert_double`.

`pressure` *Traced thermal hydraulic regime*. Traced pressure of heat carrier (water) for each pipe in tracing path enumerated along the direction of flow, [*MPa*]. Type: `assert_double`.

`flow_rate` *Traced thermal hydraulic regime*. Traced flow rate of heat carrier (water) for each pipe in tracing path enumerated along the direction of flow, [*ton/hour*]. Type: `assert_double`.

`loss` User-provided specific heat loss power for each pipe in tracing path enumerated along the direction of flow, [*kcal/m/h*], - copy of input. Type: `assert_double`.

`flux` Heat flux for each pipe in tracing path enumerated along the direction of flow, [*W/m^2*]. Type: `assert_double`.

`Q` Heat loss for each pipe in tracing path enumerated along the direction of flow per day, [*kcal*]. Type: `assert_double`.

Type: `assert_list`.

See Also

Other Regime tracing: `m325tracebw()`, `m325tracefw()`, `m325traceline()`, `tracebw()`, `tracefw()`

Examples

```
library(pipenostics)

# Consider 4-segment tracing path.
```

```
# First, let sensor readings for forward tracing:
t_fw <- 130  # [°C]
p_fw <- mpa_kgf(6)*all.equal(.588399, mpa_kgf(6))  # [MPa]
g_fw <- 250  # [ton/hour]

# Let discharges to network for each pipeline segment are somehow determined as
discharges <- seq(0, 30, 10)  # [ton/hour]

# Experimentally obtained values of specific heat loss power are
actual_loss <- c(348.0000, 347.1389, 346.3483, 345.8610)

# Then the calculated regime (red squares) for forward tracing is
regime_fw <- traceline(t_fw, p_fw, g_fw, discharges, loss = actual_loss, forward = TRUE)
print(regime_fw)

# $temperature
# [1] 129.1799 128.4269 127.9628 127.3367
#
# $pressure
# [1] 0.5878607 0.5874226 0.5872143 0.5870330
#
# $flow_rate
# [1] 250 240 220 190
#
# $loss
# [1] 348.0000 347.1389 346.3483 345.8610
#
# $flux
# [1] 181.9600 181.5097 181.0963 180.8415
#
# $Q
# [1] 5011200 4415607 2493707 2905232


# Next consider values of traced regime as sensor readings for backward tracing:
t_bw <- 127.3367  # [°C]
p_bw <- .5870330  # [MPa]
g_bw <- 190  # [ton/hour]

# Then the calculated regime (red squares) for backward tracing is
regime_bw <- traceline(t_bw, p_bw, g_bw, discharges, loss = actual_loss, forward = FALSE)
print(regime_bw)

# $temperature
# [1] 130.000893685 129.180497939 128.427226907 127.963046346
#
# $pressure
# [1] 0.588399833660 0.587861095778 0.587422779315 0.587214377798
#
# $flow_rate
# [1] 250 250 240 220
#
# $loss
```

```
# [1] 348.0000 347.1389 346.3483 345.8610
#
# $flux
# [1] 181.959958158 181.509711836 181.096328092 180.841531863
#
# $Q
# [1] 5011200.000 4415606.808 2493707.760 2905232.400

# Let compare sensor readings with backward tracing results:
tracing <- with(regime_bw, {
  lambda <- function(val, constraint)
    c(val, constraint, constraint - val,
      abs(constraint - val)*100/constraint)
  first <- 1
  structure(
    rbind(
      lambda(temperature[first], t_fw),
      lambda(pressure[first],    p_fw),
      lambda(flow_rate[first], g_fw)
    ),
    dimnames = list(
      c("temperature", "pressure", "flow_rate"),
      c("sensor.value", "traced.value", "abs.discr", "rel.discr")
    )
  )
})
print(tracing)

# sensor.value   traced.value          abs.discr         rel.discr
# temperature 130.00089368526 130.0000000000 -8.93685255676e-04 0.000687450196674
# pressure      0.58839983366   0.5883990075 -8.26160099998e-07 0.000140408139624
# flow_rate   250.00000000000 250.0000000000  0.00000000000e+00 0.000000000000000
```

---

wth_d *Derive the wall thickness depending on the outside diameter of pipe*

Description

Use GOST 30732 specifications to derive the value of the pipe wall thickness if only its diameter is known for the pipe.

Usage

```
wth_d(x)
```

Arguments

x	outside diameter of pipe, [*mm*]. Type: assert_double.

Details

Utility should be used only in cases where the actual value of the pipe wall thickness cannot be determined by any other means. In many cases internal diameter may be used instead of outside one without significant loss in precision. The wall thickness value is derived only for the diameters mentioned in Minenergo Order 325.

Unfortunately, the inverse function cannot be constructed in any reliable way due to significant ambiguity.

References

GOST 30732. *Steel pipes and shaped products with foamed polyurethane thermal insulation in protective sheath. Specifications.*

See Also

Other utils: `geoarea()`, `meteos()`, `mgtdhid()`

Examples

```
library(pipenostics)

# Guess pipe widths for some frequently met diameters
wth_d(as.double(c(57, 76, 89)))

# [1]  3  7 11  # [mm]
```

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