Package 'pipenostics'

February 18, 2021

Type Package

Title Diagnostics, Reliability and Predictive Maintenance of Pipeline Systems

Version 0.1.4

Description Functions representing some useful empirical and data-driven models of heat losses, corrosion diagnostics, reliability and predictive maintenance of pipeline systems. The package is an option for digital transformation of technical engineering departments of heat generating and heat transferring companies.

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

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

License GPL-3

Encoding UTF-8

LazyData true

Depends R (¿= 3.5.0)

Imports checkmate

RoxygenNote 7.1.1

Suggests testthat (¿= 3.0.0), covr

Config/testthat/edition 3

NeedsCompilation no

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R topics documented:

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

wth nominal wall thickness of the 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 the 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

```
## 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 the pipe, [*PSI*]. Type: assert_double.
maop	maximum allowable operating pressure - *MAOP*, [*PSI*]. Type: assert_double.
d	nominal outside diameter of the pipe, [*inch*]. Type: assert_double.
wth	nominal wall thickness of the 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

```
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 the pipe, [*PSI*]. Type: assert_double.
maop	maximum allowable operating pressure - *MAOP*, [*PSI*]. Type: assert_double.
d	nominal outside diameter of the pipe, [*inch*]. Type: assert_double.
wth	nominal wall thickness of the 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

```
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 zone.

Usage

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

Arguments

`d`	nominal outside diameter of the pipe, [*inch*]. Type: `assert_double`.
`wth`	nominal wall thickness of the 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

```
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 the pipe, [*inch*]. Type: `assert_double`.

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

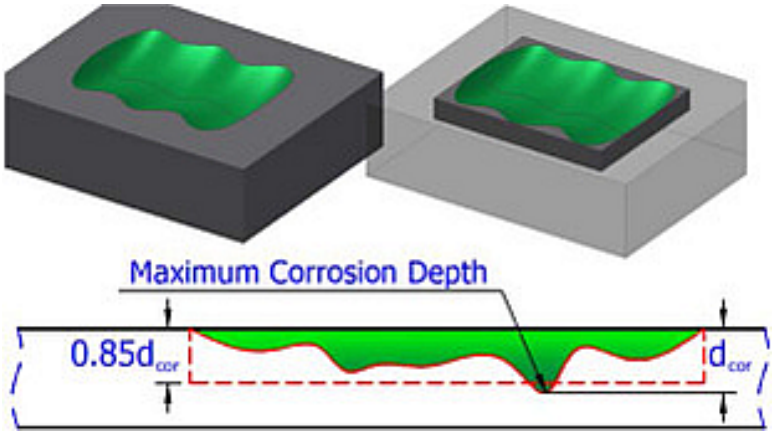
```
b31gdep(30, .438, 52e3, .72)
# [1] 1093.748  # [PSI]
```

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

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

Value

Operational status of pipe:

- *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

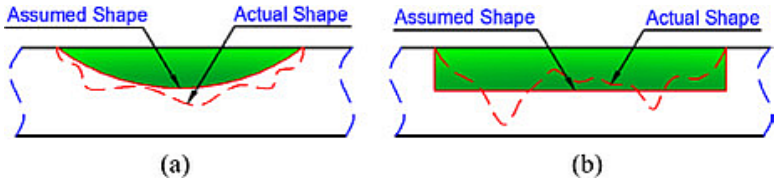
```
b31gops(.438, .1)
# [1] 2  # typical status for the most of pipes

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 the pipe, [*inch*]. Type: `assert_double`.
`wth`	nominal wall thickness of the 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 `NA`s 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

```
## 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 the pipe, [*PSI*]. Type: assert_double.
d	nominal outside diameter of the pipe, [*inch*]. Type: assert_double.
wth	nominal wall thickness of the 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

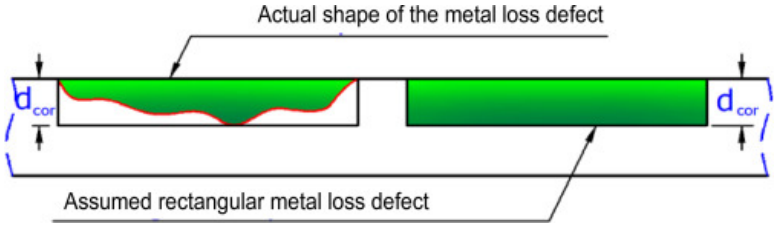
```
b31gsap(1093, 30, .438, .1, 7.5)
# [1] 1093  # [PSI], safe pressure is equal to design pressure

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

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 the pipe, [*mm*]. Type: `assert_double`.
`wth`	nominal wall thickness of the 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

```
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` *Consumption drop in pipe*

Description

Calculate *drop* or *recovery* of consumption 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 consumption in the outlet of pipe under consideration. When the calculated value is negative they have the *recovery*, i.e. the increase of consumption in the outlet of pipe under consideration. In both cases to calculate consumption on the outlet of pipe under consideration simply subtract the calculated value from the sensor-measured consumption on the inlet.

Usage

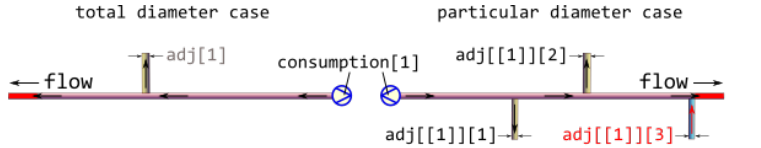
```
dropg(adj = 0, d = 700, consumption = 250)
```

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`.
`consumption`	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 consumption undergoes discharges to network and recharges from it. For calculation of consumption *drop* or *recovery* the next configuration of district heating network segment is assumed:



- consumption sensor
- calculated consumption drop
- pipe under sonsideration
- adjacent pipe for discharge to network
- adjacent pipe for recharge from network

adj[1]- total diameter of all adjacent pipes (positive or negative value)
adj[[1]][1]- diameter of discharge pipe (positive value)
adj[[1]][3]- diameter of recharge pipe (negative value)

Usually, there are no additional sensors that could measure consumption 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 consumption *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

consumption *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 consumption on the outlet of pipe under consideration simply subtract the calculated value from the sensor-measured consumption on the inlet. Type: `assert_double`.

See Also

Other district heating: dropp(), dropt()

Examples

```
# 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 consumption in the inlet of the pipe
# under consideration be proportional to d, [ton/hour]:
consumption <- .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 consumption on the outlet of the pipe under consideration,
# [ton/hour]

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

# [1]  75.96439 134.72222  65.70302 180.80580  78.05995

# For more clarity they may perform calculations in data.table:
## Not run:
dataset <- data.table::data.table(adj, d, consumption)
print(dataset)

#     adj    d consumption
# 1:  450  800       100.0
# 2: -400  900       112.5
# 3:  950 1000       125.0
# 4: -255 1400       175.0
# 5: 1152 1200       150.0

dataset[, drop := dropg(adj, d, consumption)]  # calculate drop and recovery
dataset[, result := consumption - drop]
print(dataset)

#     adj    d consumption       drop    result
# 1:  450  800       100.0  24.035608  75.96439
# 2: -400  900       112.5 -22.222222 134.72222
# 3:  950 1000       125.0  59.296978  65.70302
# 4: -255 1400       175.0  -5.805804 180.80580
# 5: 1152 1200       150.0  71.940050  78.05995
```

```
## End(Not run)

# Now let consider particular diameter case with the same total diameters of
# adjacent pipes, [mm]:

adjp <- list(
 c(100, 175, 175, -65, 125, -60),  # diameters of 4 discharge pipes and 2 recharge pipes, [mm]
  c(-300, -100, -65, 125, -60),  # diameter of 1 discharge pipe and 4 recharge pipes, [mm]
  c(950),  # diameter of 1 discharge pipe, [mm]
  c(-255), # diameter of 1 recharge pipe, [mm]
  c(50, 70, 1000, 32)  # diameter of 4 discharge pipes, [mm]
)

stopifnot(
  all(sapply(adjp, sum) == adj)
)

# Recalculate the result:
result2 <- consumption - dropg(adjp, d, consumption)
stopifnot(
  all(result == result2)
)

# They may do it in data.table:
## Not run:
dataset <- data.table::data.table(adjp, d, consumption)
print(dataset)

#                        adjp    d consumption
# 1:  100,175,175,-65,125,-60  800       100.0
# 2: -300,-100, -65, 125, -60  900       112.5
# 3:                       950 1000       125.0
# 4:                      -255 1400       175.0
# 5:        50,  70,1000,  32 1200       150.0

dataset[, drop := dropg(adj, d, consumption)]  # calculate drop and recovery
dataset[, result := consumption - drop]
print(dataset)

#                         adjp    d consumption       drop    result
# 1:  100,175,175,-65,125,-60  800       100.0  24.035608  75.96439
# 2: -300,-100, -65, 125, -60  900       112.5 -22.222222 134.72222
# 3:                       950 1000       125.0  59.296978  65.70302
# 4:                      -255 1400       175.0  -5.805804 180.80580
# 5:        50,  70,1000,  32 1200       150.0  71.940050  78.05995

## End(Not run)
```

---

dropp *Pressure drop in pipe*

Description

Calculate pressure drop in straight circular 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),
  consumption = 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`.
`consumption`	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**)

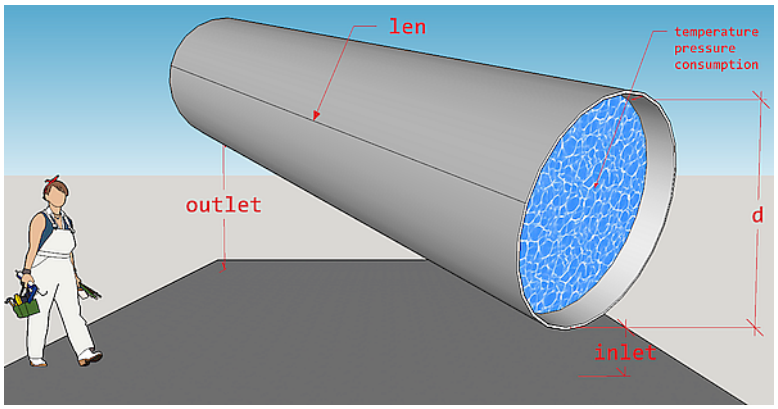
Details

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`, `consumption`). 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 the 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

```
# 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 pipe due heat losses*

Description

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

Usage

```
dropt(temperature = 130, pressure = mpa_kgf(6), consumption = 250, flux = 7000)
```

Arguments

`temperature`	temperature of heat carrier (water) inside the pipe measured at the inlet of pipe, [$^{\circ}C$]. Type: `assert_double`.
`pressure`	absolute pressure of heat carrier (water) inside the pipe, [MPa]. Type: `assert_double`.
`consumption`	amount of heat carrier (water) that is transferred by pipe during a period, [$ton/hour$]. Type: `assert_double`.
`flux`	heat flux emitted by pipe during a period, [$kcal/hour$]. 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, [$^{\circ}C$]. Type: assert_double.

See Also

m325dropt for calculating normative values of temperature drop

Other district heating: dropg(), dropp()

Examples

```
# Calculate normative temperature drop based on Minenergo-325 for pipe segment
pipeline <- list(
  year = 1968,
  laying = "channel",
  d = 700,
  l = 1000
)
operation_temperature <- c(130, 150)  # [°C]

foo <- dropt(
  temperature = operation_temperature,
  flux = do.call(
    m325nhl,
    c(pipeline, temperature = list(operation_temperature))
  )
)

foo
# 1.37 [°C]

# This is the same as using m325dropt:
bar <- m325dropt(temperature = operation_temperature,
  year = 1968, laying = "channel", d = 700, l = 1000
)

stopifnot(all.equal(foo, bar))
```

---

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", maxcores = 2)
```

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.
maxcores	maximum cores of CPU to use in parallel processing. Type: assert_count.

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.

For possibly better performance, they search paths of heat carrier flow in parallel leveraging the functionality of package parallel.

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

```
## Not run:
# 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)
})

# dummy element-wise test:
for (i in union(seq_along(path), seq_along(all_paths)))
  stopifnot(path[[i]] == all_paths[[i]])

## End(Not run)
```

`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 utils: `kgf_mpa()`, `mm_inch()`, `mpa_kgf()`, `mpa_psi()`, `psi_mpa()`

Examples

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

## unit test:
stopifnot(round(inch_mm(c(25.4, 1)), 8) == c(1.0, 0.03937008))
```

---

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 utils: inch_mm(), mm_inch(), mpa_kgf(), mpa_psi(), psi_mpa()

Examples

```
## unit test:
stopifnot(
  all.equal(
    kgf_mpa(c(0.0980665, 1)),
    c(1.0000000, 10.197162)
  )
)
```

`m278hlair` *Minenergo-278. Heat losses of overhead pipeline segment*

Description

Calculate values of heat flux emitted by overhead pipeline segment (surrounded by air) 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, $[^{\circ}C]$. Type: `assert_double`.
`t2`	temperature of heat carrier (water) inside the returning pipe, $[^{\circ}C]$. Type: `assert_double`.
`t0`	temperature of environment, $[^{\circ}C]$. In case of overhead laying 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`	external diameter of supplying pipe, $[m]$. Type: `assert_double`.
`d2`	external diameter of returning pipe, $[m]$. Type: `assert_double`.

`lambda1`	thermal conductivity of insulator which covers the supplying pipe $[W/m/^{\circ}C]$. Type: `assert_double`.
`lambda2`	thermal conductivity of insulator which covers the returning pipe $[W/m/^{\circ}C]$. `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, $[W/m/^{\circ}C]$. In case of overhead laying this is the thermal conductivity of open air. Type: `assert_double`.
`len`	length of pipeline segment, $[m]$. Type: `assert_double`.
`duration`	duration of heat flux emittance, $[hour]$. Type: `assert_double`.

Details

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

Value

Heat flux emitted by pipeline segment during `duration`, $[kcal]$. If `len` of pipeline segment is 1 m and `duration` of heat flux emittance is set to 1 $hour$ then the return value is equal to that in $[kcal/m/h]$ units and so comparable with values of heat flux listed in Minenergo Order 325. Type: `assert_double`.

See Also

Other Minenergo: `m278hlcha()`, `m278hlund()`, `m278insdata`, `m278inshcm()`, `m278soildata`, `m325beta()`, `m325dropt()`, `m325nhldata`, `m325nhl()`, `m325testbench`

Examples

```
## Dummy test:
stopifnot(round(m278hlair(), 3) == 138.774)
```

`m278hlcha` *Minenergo-278. Heat losses of pipeline segment in channel*

Description

Calculate values of heat flux emitted by pipeline segment mounted in 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, [$^{\circ}C$]. Type: assert_double.
t2	temperature of heat carrier (water) inside the returning pipe, [$^{\circ}C$]. Type: assert_double.
t0	temperature of environment, [$^{\circ}C$]. 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	external diameter of supplying pipe, [m]. Type: assert_double.
d2	external diameter of returning pipe, [m]. Type: assert_double.
lambda1	thermal conductivity of insulator which covers the supplying pipe [$W/m/^{\circ}C$]. Type: assert_double.
lambda2	thermal conductivity of insulator which covers the returning pipe [$W/m/^{\circ}C$]. 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, [$W/m/^{\circ}C$]. 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 pipeline segment, [m]. Type: assert_double.
duration	duration of heat flux emittance, [$hour$]. Type: assert_double.

Details

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

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

Value

Heat flux emitted by pipeline segment during duration, [$kcal$]. If len of pipeline segment is 1 m and duration of heat flux emittance is set to 1 $hour$ then the return value is equal to that in [$kcal/m/h$] units and so comparable with values of heat flux listed in Minenergo Order 325. Type: assert_double.

See Also

Other Minenergo: m278hlair(), m278hlund(), m278insdata, m278inshcm(), m278soildata, m325beta(), m325dropt(), m325nhldata, m325nhl(), m325testbench

Examples

```
## Dummy test:
stopifnot(round(m278hlcha(), 3) == 86.930)

## Naive way to find out technical state (factors k1 and k2) for pipe
## segments constructed in 1980:
stopifnot(
  round(
    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) == c(4.3, 4.3) # c(k1, k2)
)
```

`m278hlund` *Minenergo-278. Heat losses of underground pipeline segment*

Description

Calculate values of heat flux emitted by underground pipeline segment which is not mounted in 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

```
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, [$^{\circ}C$]. Type: `assert_double`.
`t2`	temperature of heat carrier (water) inside the returning pipe, [$^{\circ}C$]. Type: `assert_double`.
`t0`	temperature of environment, [$^{\circ}C$]. In case of underground 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`	external diameter of supplying pipe, [m]. Type: `assert_double`.

d2	external diameter of returning pipe, $[m]$. Type: assert_double.
lambda1	thermal conductivity of insulator which covers the supplying pipe $[W/m/^{\circ}C]$. Type: assert_double.
lambda2	thermal conductivity of insulator which covers the returning pipe $[W/m/^{\circ}C]$. 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, $[W/m/^{\circ}C]$. In case of underground laying this is the thermal conductivity of subsoil. Type: assert_double.
z	underground laying depth, $[m]$. Type: assert_double.
s	distance between supplying and returning pipes, $[m]$. Type: assert_double.
len	length of pipeline segment, $[m]$. Type: assert_double.
duration	duration of heat flux emittance, $[hour]$. Type: assert_double.

Details

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

Value

Heat flux emitted by pipeline segment during duration, $[kcal]$. If len of pipeline segment is 1 m and duration of heat flux emittance is set to 1 $hour$ then the return value is equal to that in $[kcal/m/h]$ units and so comparable with values of heat flux listed in Minenergo Order 325. Type: assert_double.

See Also

Other Minenergo: m278hlair(), m278hlcha(), m278insdata, m278inshcm(), m278soildata, m325beta(), m325dropt(), m325nhldata, m325nhl(), m325testbench

Examples

```
## Dummy test:
stopifnot(round(m278hlund(), 3) == 102.623)
```

---

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, $[mW/m/^{\circ}C]$. Type: assert_integer.

k Value for factor. Type: assert_integer.

Details

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

Source

http://www.complexdoc.ru/ntdtext/547103/

See Also

Other Minenergo: m278hlair(), m278hlcha(), m278hlund(), m278inshcm(), m278soildata, m325beta(), m325dropt(), m325nhldata, m325nhl(), 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, $[^{\circ}C]$. Type: assert_double.
material	designation of insulation material as it stated in m278insdata, Type: assert_subset.

Value

Thermal conductivity of insulation materials $[W/m/^{\circ}C]$ at given set of temperatures. Type: `assert_double`.

See Also

Other Minenergo: `m278hlair()`, `m278hlcha()`, `m278hlund()`, `m278insdata`, `m278soildata`, `m325beta()`, `m325dropt()`, `m325nhldata`, `m325nhl()`, `m325testbench`

Examples

```
# Averaged thermal conductivity of pipe insulation at 110 °C
print(m278insdata)
stopifnot(
  round(
    mean(with(m278insdata, { m278inshcm(110, material)})),
    2) == 9e-2
)

# Terms for linear connection between thermal conductivity of unknown
# (averaged) pipe insulator vs temperature:
temperature <- as.double(1:450)
lambda_ins <- with(m278insdata, {
  vapply(temperature, function(x) mean(m278inshcm(x, material)), .1)
})
C <- coef(lsfit(temperature, lambda_ins))  # c(Intercept, X)
stopifnot(
  all(abs(C - c(7.963590e-02, 9.730769e-05)) < 1e-8)
)
```

---

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, [$W/m/^{\circ}C$]. Type: assert_double.

Source

http://www.complexdoc.ru/ntdtext/547103/

See Also

Other Minenergo: m278hlair(), m278hlcha(), m278hlund(), m278insdata, m278inshcm(), m325beta(), m325dropt(), m325nhldata, m325nhl(), 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 losses of pipe by taking into account heat losses 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`, `m325dropt()`, `m325nhldata`, `m325nhl()`, `m325testbench`

Examples

```
norms <- within(m325nhldata, {
  beta <- m325beta(laying, as.double(diameter))
})
```

`m325dropt` *Minenergo-325. Temperature drop in pipe due heat losses*

Description

Calculate temperature drop in steel pipe of *district heating system* (where water is a heat carrier) that is a result of heat losses through pipe wall and insulation using Minenergo Order 325 as a basis for values of heating flux.

Since Minenergo Order 325 is used as the basis for values of heating flux the calculated temperature drop may be considered as a *normative temperature drop*. If the actual (somehow measured) temperature drop is more than this *normative temperature drop* they may consider such difference to be due to *extra-normative heat losses*. The presence of the latter requires appropriate maintenance activities.

Usage

```
m325dropt(
  temperature = 130,
  pressure = mpa_kgf(6),
  consumption = 250,
  d = 700,
  len = 1,
  year = 1986,
  insulation = 0,
  laying = "underground",
  beta = FALSE,
  exp5k = TRUE
)
```

Arguments

`temperature`	temperature of heat carrier (water) inside the pipe measured at the entrance of pipe, $[^{\circ}C]$. Type: `assert_double`.
`pressure`	absolute pressure of heat carrier (water) inside the pipe, $[MPa]$. Type: `assert_double`.

`consumption` amount of heat carrier (water) that is transferred by pipe during a period, [*ton/hour*]. Type: `assert_double`.

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

`len` length of pipe, [*m*]. Type: `assert_double`.

`year` year when the pipe is put in operation after laying or total overhaul. Type: `assert_integerish`.

`insulation` insulation that covers the exterior of pipe:

`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:

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

Type: `assert_subset`.

`beta` should they consider additional heat losses of fittings? Type: `assert_logical`.

`exp5k` pipe regime flag: is pipe operated more that 5000 hours per year? Type: `assert_logical`.

Details

The function is a simple wrapper for call of `dropt` with parameter `flux` calculated by `m325nhl`.

Value

normative temperature drop at the outlet of pipe, [$^{\circ}C$]. Type: `assert_double`.

See Also

`dropt` for calculating temperature drop in pipe using actual heat flux values

Other Minenergo: `m278hlair()`, `m278hlcha()`, `m278hlund()`, `m278insdata`, `m278inshcm()`, `m278soildata`, `m325beta()`, `m325nhldata`, `m325nhl()`, `m325testbench`

Examples

```
stopifnot(
  round(
    m325dropt(
      temperature = 130, year = 1968, laying = "channel", d = 700, l = 1000
    ), 2) == 1.37
)
```

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

Description

Calculate normative values of heat flux that is legally affirmed by Minenergo Order 325 to be emitted by steel pipe of district heating system with water as a heat carrier.

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, $[°C]$. Type: `assert_double`.

`len`	length of pipe, $[m]$. Type: `assert_double`.
`duration`	duration of heat flux emittance, $[hour]$. Type: `assert_double`.
`beta`	should they consider additional heat losses 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

Heat flux emitted by pipe during `duration`, $[kcal]$. If `len` of pipe is 1 m and `duration` of heat flux emittance is set to 1 $hour$ then the return value is in the same units as value of heat flux, $[kcal/m/h]$, accepted by Minenergo Order 325. Type: `assert_double`.

See Also

Other Minenergo: `m278hlair()`, `m278hlcha()`, `m278hlund()`, `m278insdata`, `m278inshcm()`, `m278soildata`, `m325beta()`, `m325dropt()`, `m325nhldata`, `m325testbench`

Examples

```
with(m325nhldata, {

## Linear extrapolation adopted in Minenergo's Order 325 using last two points:
temperature <- seq(0, 270, 10)  # [°C]
flux <- m325nhl(1980, "underground", TRUE, 0, 73, temperature)  # [kcal/m/h]
plot(temperature, flux, type = "b")

## Consider heat losses of fittings:
stopifnot(
  ## when beta becomes 1.15
  all(
    round(
      m325nhl(1980, "underground", d = 73, temperature = 65,
              beta = c(FALSE, TRUE)),
      3
    ) == c(65.500, 75.325)
  ),

  ## when beta becomes 1.2
  all(
    round(
      m325nhl(2000, "channel", d = 73, temperature = 65,
              beta = c(FALSE, TRUE)),
```

```
        3
      ) == c(17.533, 21.040)
    )
  )
})
```

`m325nhldata` *Minenergo-325. Data for normative heat losses of pipe*

Description

Data represent values of heat losses officially accepted by Minenergo Order 325 as norms. Those values represent heat flux that is legally affirmed to be emitted per meter during an hour by steel pipe of district heating system 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.

flux Heat flux emitted by every meter of 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

http://docs.cntd.ru/document/902148459

See Also

Other Minenergo: m278hlair(), m278hlcha(), m278hlund(), m278insdata, m278inshcm(), m278soildata, m325beta(), m325dropt(), 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. NAs 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.

consumption 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 consumption 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 losses 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`.

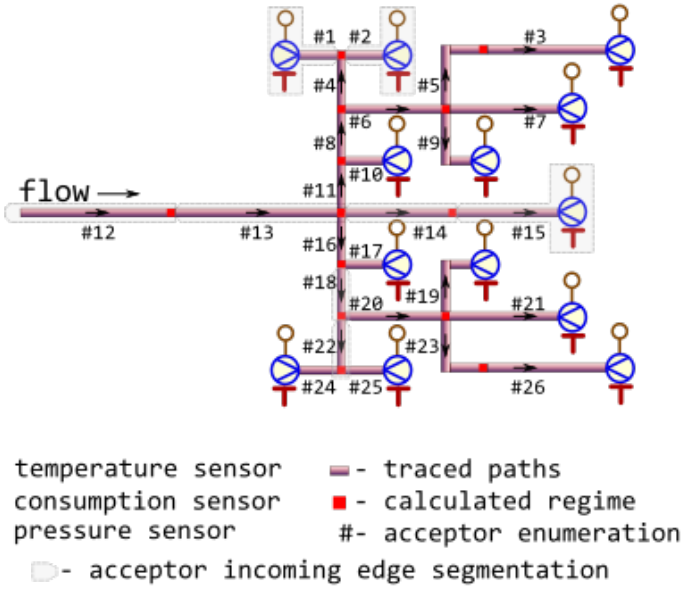
roughness roughness of internal wall of pipe (i.e. acceptor's incoming edge), $[m]$. Type: `assert_double`.

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()`, `m325dropt()`, `m325nhldata`, `m325nhl()`

Examples

```
## Not run:
# Do not hesitate to use data.table for larger chunks of network:
library(data.table)
setDT(m325testbench)

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

# Do all terminal nodes have sensor-measured regime parameters?:
terminal_nodes <- m325testbench[!(acceptor %in% sender)]
```

```
stopifnot(
  all(!is.na(terminal_nodes[, .(temperature, pressure, consumption)]))
)

# Welcome to use igraph for topology investigations:
library(igraph)
g <- graph_from_data_frame(
# provide edge list with edge attributes:
  d = m325testbench[,
                    .SD,
                .SDcols = !c("temperature", "pressure", "consumption", "inlet", "outlet")
  ],

  # provide node attributes:
  v = rbind(
    # attributes for zero sender
    list(
      acceptor = 0, elevation = NA_real_, temperature = NA_real_,
      pressure = NA_real_, consumption= NA_real_
    ),
    m325testbench[,
                  .(
                    # Since every row describes node with its incoming edge:
                    acceptor, elevation = outlet,
                    # sensor readings (if any):
                    temperature, pressure, consumption
                  )
    ]
  )
)

plot(g, layout = layout_as_tree(g, root = 1))

## End(Not run)
```

`m325tracebw` *Minenergo-325. Trace backwards thermal-hydraulic regime for district heating network*

Description

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

Usage

```
m325tracebw(
  sender = 6,
  acceptor = 7,
```

```
  temperature = 70,
  pressure = pipenostics::mpa_kgf(6),
  consumption = 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`	*snapshot of thermal-hydraulic regime state*: temperature of heat carrier (water) sensor-measured on the terminal acceptor node, $[^{\circ}C]$. Use `NA_float_`s for nodes without temperature sensor. Type: `assert_double`.
`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`.
`consumption`	*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`. Use `NA_float_`s for nodes without consumption 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 losses 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_logical`.

`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`.

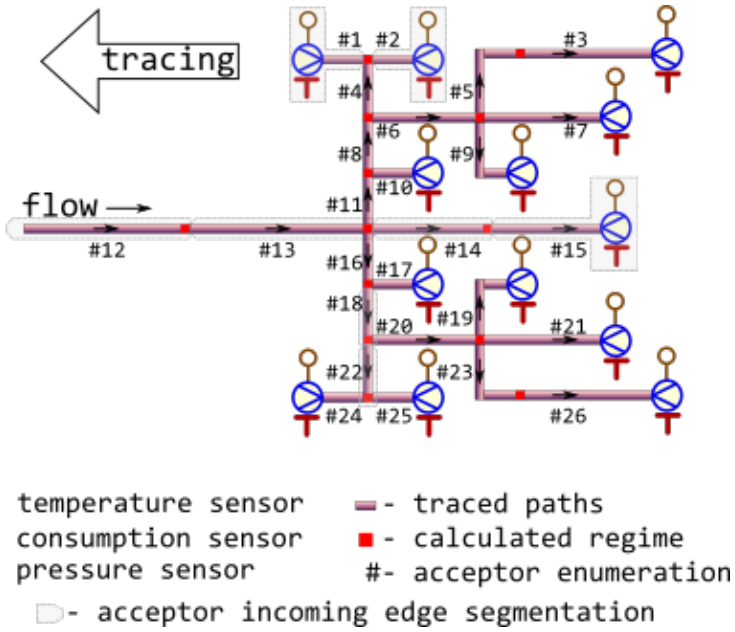
`csv` logical indicator: should they incrementally dump results to *csv*-file while tracing? Type: `assert_flag`.

`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

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 much similar to `m325testbench`:



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 temperature or pressure at the node 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 consumption at the node is always `sum`.

Value

`data.frame` containing results of tracing in long format (narrow format) mostly like it returned by function `m325tracefw`:

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

`trace` concatenated 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` identifier of tracing direction. It constantly equals to `TRUE`. Type: `assert_logical`.

`aggregation` aggregation method associated with values of calculated temperature or pressure in `data.frame`'s row for the node:

`identity` values (opinions) of temperature or pressure as they are (no aggregation).

`span` span of values (opinions) of temperature or pressure for the node

`median` median of values (opinions) of temperature or pressure for the node

`mean` avaraged values (opinions) temperature or pressure for the node

Type: assert_character.

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

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

`consumption` *snapshot of thermal-hydraulic regime state*: traced pressure of heat carrier (water) that is associated with the node, [*ton/hour*] Type: assert_double.

`job` value of trace step counter. Type: assert_integer.

See Also

Other Regime tracing: m325tracefw(), m325traceline()

Examples

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

# Get isomorphic representation of district heating network graph:
nx <- pipenostics::m325testbench
nx$d <- 1e3*nx$d  # convert [m] to [mm]

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

# Distinct options for opinion aggregation lead to distinct traced
# temperature and pressure:
output <- list(
  mean   = do.call("m325tracebw",
                   c(as.list(nx), verbose = FALSE, opinion = "mean")),
  median = do.call("m325tracebw",
                   c(as.list(nx), verbose = FALSE, opinion = "median"))
)

stopifnot(
  round(
    subset(
      output$mean,
      node == 13 & aggregation == "median",
      c("temperature", "pressure", "consumption")
    ) - subset(
      output$median,
      node == 13 & aggregation == "median",
      c("temperature", "pressure", "consumption")
    ),
    5
    # difference between aggregation options
  ) == c(dt = 0.03732, dp = 0.00139, dg = 0)
```

```
)

# Do not hesitate to use along with data.table...
## Not run:
data.table::setDT(nx)
result <-
  nx[, m325tracebw(sender, acceptor, temperature, pressure, consumption, d, len,
                   year, insulation, laying, beta, exp5k, roughness, inlet,
                   outlet, method = "romeo", verbose = TRUE, opinion = "median",
                   csv = FALSE, file = "m325tracebw.csv")]

# ...but mind that the obtained result should go to independent data.frame:
stopifnot(is.data.frame(result) & !is.data.table(result))

## End(Not run)
```

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

Description

Trace values of thermal-hydraulic regime (temperature, pressure, consumption) in the bunched pipeline along the flow direction using norms of heat flux 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_),
  consumption = 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",
  maxcores = 2
)
```

Arguments

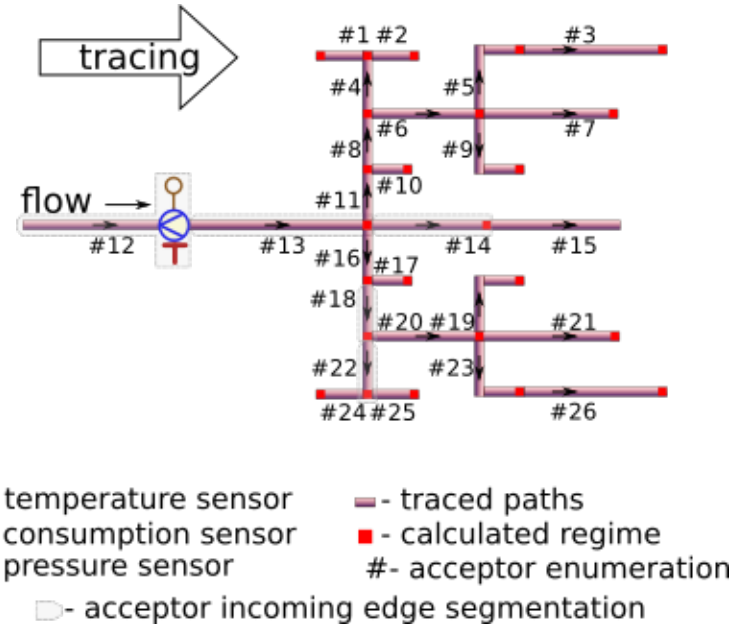
sender	identifier of the node which heat carrier flows out. Type: any type that can be painlessly coerced to character by as.character.
acceptor	identifier of the node which heat carrier flows in. According to topology of test bench considered this identifier should be unique for every row. Type: any type that can be painlessly coerced to character by as.character.
temperature	*snapshot of thermal-hydraulic regime state*: temperature of heat carrier (water) sensor-measured on the root node, $[^{\circ}C]$. Type: assert_double. Use NA_float_s 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. Use NA_float_s for nodes without pressure sensor.
consumption	*snapshot of thermal-hydraulic regime state*: sensor-measured amount of heat carrier (water) on root 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 consumption 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 losses 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.
`maxcores`	maximum cores of CPU to use in parallel processing. Type: `assert_count`.

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 much similar to `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 of tracing in long format (narrow format) mostly like it returned by function `m325tracebw`:

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

`trace` 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` identifier of tracing direction. It constantly equals to `FALSE`. Type: `assert_logical`.

`aggregation` aggregation method associated with values of calculated temperature or pressure in `data.frame`'s row for the node. For forward tracing the only option is `identity`. Type: `assert_character`.

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

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

`consumption` *snapshot of thermal-hydraulic regime state*: traced pressure of heat carrier (water) that is associated with the node, [*ton/hour*] Type: `assert_double`.

`job` value of trace step counter. For forward tracing value of `job` counts the number of traced paths from root node. Type: `assert_integer`.

See Also

Other Regime tracing: `m325tracebw()`, `m325traceline()`

Examples

```
## Not run:
# Minimum two nodes should be in district heating network graph:
m325tracefw(verbose = FALSE)
```

```
# node  trace backward aggregation temperature  pressure consumption job
# 1    1 sensor    FALSE    identity    70.00000 0.5883990          20   0
# 2    2      1    FALSE    identity    69.71603 0.5813153          20   1

# Example with the test bench:
nx <- pipenostics::m325testbench

# avoid using numeric identifiers for nodes:
nx$sender <- paste0("N", nx$sender)
nx$acceptor <- paste0("N", nx$acceptor)

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

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

# Put the traced values to the root node of the test bench:
root_node_idx <- 12
root_node <- paste0("N", root_node_idx)
regime_param  <- c("temperature", "pressure", "consumption")
nx[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(nx), 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(nx, !(acceptor %in% sender))$acceptor &
    aggregation == "identity"
)

regime_delta <- colMeans(
  subset(report, backward, regime_param) -
    subset(report, !backward, regime_param)
)
print(regime_delta)
# temperature      pressure   consumption
# -4.640201e-01 -5.208802e-03 -5.465713e-16

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

## End(Not run)
```

`m325traceline` *Minenergo-325. Trace thermal-hydraulic regime for linear segment*

Description

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

Usage

```
m325traceline(
  temperature = 130,
  pressure = mpa_kgf(6),
  consumption = 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`	temperature of heat carrier (water) inside the pipe sensor-measured at the inlet (forward tracing) or at the outlet (backward tracing) of path, [$^{\circ}C$]. Type: `assert_number`.
`pressure`	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`.
`consumption`	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 consumption 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 — should they consider additional heat losses of fittings? Logical value for each pipe in tracing path enumerated along the direction of flow. Type: assert_logical.

exp5k — pipe regime flag: 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`.

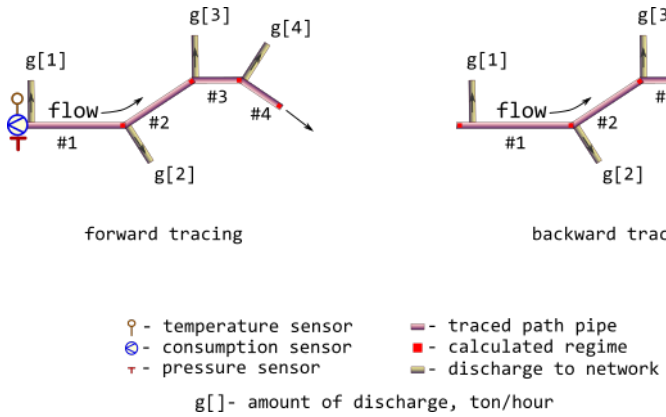
`forward` tracing direction flag: is it a forward direction of tracing? If `FALSE` the backward tracing is performed. Type: `assert_flag`.

`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 consumption 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`.

Value

named list of regime parameters for the traced path with the next elements:

`temperature` calculated temperatures of heat carrier for all pipeline segments, [$^{\circ}C$]. Type: `assert_double`.

`pressure` calculated pressures of heat carrier for all pipeline segments, [MPa]. Type: `assert_double`.

`consumption` calculated consumption(s) of heat carrier for all pipeline segments, [*ton/hour*]. Type: `assert_double`.

See Also

`m325dropt` for calculating normative temperature drop in single pipeline segment

Other Regime tracing: `m325tracebw()`, `m325tracefw()`

Examples

```
# Consider 4-segment tracing path depicted in ?m325regtrace help page.
# First, let sensor readings for forward tracing:
t_fw <- 130  # [°C]
p_fw <- .588399*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
#
# $consumption
# [1] 250 240 220 190

# 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
#
# $consumption
# [1] 250 250 240 220

# 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(consumption[first], g_fw)
    ),
    dimnames = list(
      c("temperature", "pressure", "consumption"),
      c("sensor.value", "traced.value", "abs.discr", "rel.discr")
    )
  )
})
print(tracing)

# sensor.value traced.value     abs.discr    rel.discr
# temperature   130.000000  129.9952943  4.705723e-03 0.0036197868
# pressure        0.588399    0.5883998 -8.290938e-07 0.0001409067
# consumption   250.000000  250.0000000  0.000000e+00 0.0000000000

# Light unit test:
stopifnot(all(tracing[,'rel.discr'] < 4e-3))
```

`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 the *metal-loss* type:

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

leak increase of the 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(762, 100),
  wth = rep(10, 100),
  strength = rep(358.5274, 100),
  pressure = rep(0.588, 100),
  temperature = rep(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 the pipe, [*mm*]. Type: assert_double.
wth	nominal wall thickness of the 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_choice.
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, [$^{\circ}C$]. 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 `NA`s 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

```
## Not run:
# 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 the 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


# Lightweight unit test:
stopifnot(
  max(pof) > .270 && max(pof) < .274
)

## End(Not run)
```

`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 utils: inch_mm(), kgf_mpa(), mpa_kgf(), mpa_psi(), psi_mpa()

Examples

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

## unit test:
stopifnot(round(mm_inch(c(0.03937008, 1)), 1) == c(1.0, 25.4))
```

---

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 utils: inch_mm(), kgf_mpa(), mm_inch(), mpa_psi(), psi_mpa()

Examples

```
## unit test:
stopifnot(
  all.equal(
    mpa_kgf(c(10.1971619998, 1)),
    c(1.0000000, 0.0980665)
  )
)
```

`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 utils: `inch_mm()`, `kgf_mpa()`, `mm_inch()`, `mpa_kgf()`, `psi_mpa()`

Examples

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

## unit test:
stopifnot(round(mpa_psi(c(145.03773800721814, 1)), 8) == c(1, 6.89476e-3))
```

`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 the 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 the pipe, $[mm]$. Type: `assert_double`.
`wth`	nominal wall thickness of the 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**.

See Also

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

Examples

```
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
```

`pipenostics` *Diagnostics, reliability and predictive maintenance of pipeline systems*

Description

Functions representing some useful empirical and data-driven models of heat losses, corrosion diagnostics, reliability and predictive maintenance of pipeline systems. The package is an option for digital transformation of technical engineering departments of heat generating and heat transferring companies.

Author(s)

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See Also

- For further details visit the package site https://github.com/omega1x/pipenostics.
- Report bugs at github.com/omega1x/pipenostics/issues.

`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 utils: `inch_mm()`, `kgf_mpa()`, `mm_inch()`, `mpa_kgf()`, `mpa_psi()`

Examples

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

## unit test:
stopifnot(round(psi_mpa(c(6.89475728e-3, 1)), 4) == c(1, 145.0377))
```

`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 the 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 the pipe, $[mm]$. Type: `assert_double`.
`wth`	nominal wall thickness of the 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 `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. D. Ritchie, S. Last, *Burst criteria of corroded pipelines - defect acceptance criteria*, in Proceedings of the EPRG/PRC 10th Biennial Joint Technical Meeting on Line Pipe Research (Cambridge, UK, 1995)
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`, `b31gmodpf`, `dnvpf`, `pcorrcpf`

Examples

```
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, $[^{\circ}C]$. 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

```
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

# Unit test:
with(api5l3t,
     stopifnot(
       all(strderate(mpa_psi(uts), 0) - mpa_psi(uts) == 0)
     )
)
```