

PNL0003 - Compressibility + friction submodel of pneumatic pipe (C-R-C)

Description

PNL0003 is a lumped parameter submodel of a pneumatic pipe or hose with only compressibility and friction effects taking into account heat exchange.

The mass flow rates in g/s and enthalpy flow rates in J/s are input at each ports and pressures in Pa and temperatures in K are computed to be output at those ports.

The temperature and pressure at port 2 are computed using state variables.

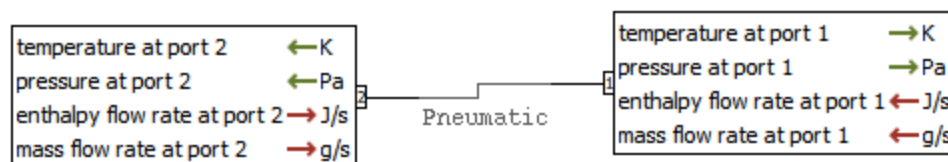
Two heat exchanges models are available:

- a simple polytropic model, which is a simplified form of the general internal energy model based on the first law of thermodynamics. The polytropic approach is obtained by representing the thermal exchange phenomena by a polytropic constant γ . In that case, the temperature and pressure are no more independent variables.
- Or a more complex model taking into account thermal exchange. For general studies, it is advised to use the thermal exchange approach.

More information on heat exchanges can be found in the documentations of [PNCH021](#) (pneumatic chamber with polytropic law) and [PNCH022](#) (pneumatic exchange with heat exchange).

Pipe friction is taken into account using a friction factor based on the Reynolds number and the relative roughness.

Icon with external variables



Usage

Use this submodel to simulate a pneumatic pipe with compressibility and friction effects, when the Mach number is low, *i.e.* gas velocity $< 0.3 \times$ speed of sound.

PNL0003 differs from [PNL0001](#) and [PNL0002](#) only in the input and output requirements.

The submodel [PNGD00](#) should be included in your circuit to define the characteristics of the gas.

Parameter settings

The *gas type index* parameter refers to a gas type defined by an icon put on the sketch.

Depending on the heat exchange model chosen:

- polytropic: the *polytropic constant* is required (> 0).
- with thermal exchange: the *thermal exchange coefficient* and the *external temperature* are required.

The relative roughness ϵ is calculated as the ratio of the average height of asperities to the tube diameter:

$$\epsilon = \frac{\Delta}{D_{eq}}$$

where:

- Δ is the equivalent uniform roughness of the pipe,
- D_{eq} is the equivalent diameter of the pipe.

A sampling of absolute pipe roughness Δ for new clean pipes is proposed by Binder :

Pipe material	Absolute roughness Δ
drawn brass	1.5 μm
drawn copper	1.5 μm
commercial steel	45 μm
wrought iron	45 μm
asphalted cast iron	120 μm
galvanized iron	150 μm
cast iron	260 μm
wood stave	0.2 to 0.9 mm
concrete	0.3 to 3 mm
riveted steel	0.9 to 9 mm

Physics and equations

Compressibility effects

The total volume of the pipe is computed from the *diameter of pipe* (D) and the *pipe length* (L) assuming a cylindrical geometry as:

$$vol = \frac{\pi \cdot D^2 \cdot L}{4}$$

With the polytropic model, the pressure and temperature derivatives are calculated using the utility [pn2vol1](#).

With the thermal exchange model, the utility [pn2vol](#) is used with a thermal exchange area given by:

$$area_{th} = \pi \cdot D \cdot L$$

Friction

The internal mass and enthalpy flow rates are calculated using the utility [pn2pipefr](#).

Heat flux

The heat flux between the tube and its surroundings is calculated as follows:

$$dh = k_{th} \cdot area_{th} \cdot (exttemp - t2)$$

with:

- (dh) the heat flux [J/s],
- (k_{th}) the thermal exchange coefficient [J/m²/K/s],
- $(area_{th})$ the thermal exchange area [m²],
- $(exttemp)$ the external temperature [K],
- $(t2)$ the fluid temperature [K].

Equivalent modeling

Equivalent models could be obtained by chaining either the submodel [PNCH012](#) or the submodel [PNL0000](#) with [PNL00R](#) and again [PNCH012](#) or [PNL0000](#).

Detailed submodel view

External variables

	Title	Variable name	Unit	Type	In/Out	Default value
Port 1						

1	temperature at port 1	t1	K	explicit state	output	293.15
2	pressure at port 1	p1	Pa	explicit state	output	0
3	enthalpy flow rate at port 1	dh1	J/s	basic variable	input	-
4	mass flow rate at port 1	dm1	g/s	basic variable	input	-
Port 2						
1	temperature at port 2	t2	K	explicit state	output	293.15
2	pressure at port 2	p2	Pa	explicit state	output	0
3	enthalpy flow rate at port 2	dh2	J/s	basic variable	input	-
4	mass flow rate at port 2	dm2	g/s	basic variable	input	-

Internal variables

	Title	Variable name	Unit	Type	Default value
1	enthalpy flow at center of pipe	dhctr	J/s	basic variable	-
2	mass flow at center of pipe	dmctr	g/s	basic variable	-
3	mass of gas in pipe	mgas	g	basic variable	-
4	Reynolds number	re	null	basic variable	-
5	mass flow parameter (cm)	cm	$(\text{kg} \cdot \text{K} / \text{J})^{**}(1/2)$	basic variable	-
6	mean gas velocity	v	m/s	basic variable	-
7	friction factor	ff	null	basic variable	-

Real parameters

	Title	Variable name	Unit	Default value
1	diameter of pipe	diam	mm	10
2	pipe length	le	m	1
3	relative roughness	rr	null	1e-05
4	polytropic constant	k	null	1.35
5	thermal exchange coefficient	kth	$\text{J} / \text{m}^{**2} / \text{K} / \text{s}$	0
6	external temperature	extemp	K	293.15

Integer parameters

	Title	Variable name	Default value
1	gas type index	gi	1
2	model	mode	2: with thermal exchange

[Contents of the Pneumatic Lines library](#)