TYPE 709: PIPE (U VALUE CALCULATED FROM PHYSICAL CHARACTERISTICS)

General Description

Very much like standard TRNSYS Type31, this component models the thermal behavior of fluid flow in a pipe or duct using variable size segments of fluid. Entering fluid shifts the position of existing segments. The mass of the new segment is equal to the flow rate multiplied by the simulation time step. The new segment's temperature is that of the incoming fluid. The outlet of this pipe is a collection of the elements that are "pushed" out by the inlet flow. This so-called "plug-flow" model does not consider mixing or conduction between adjacent elements. A maximum of 25 segments are allowed in the pipe. When the maximum is reached, the two adjacent segments with the closest temperatures are combined to make a single segment. Where Type709 differs from Type31 is that instead of asking the user to provide an overall UA value for the pipe and its insulation, the user is here asked to provide the physical characteristics of the pipe material, fluid and insulation material.

It should also be noted that the documentation for Type709 is taken largely verbatim from the documentation of Type31.

Nomenclature

Cp_{liquid}	[kJ/kg.K]	The specific heat of liquid in the pipe.
M	[kg/hr]	The total mass of liquid contained in the pipe or if subscripted, contained in a segment.
$\dot{m}$	[kg/hr]	The mass flow rate of liquid through the pipe.
$\dot{Q}_{env}$	[kJ/hr]	The rate at which energy is lost from the pipe.
t	[hrs]	Time
T	[ºC]	The temperature of the liquid.
T_i	[ºC]	The temperature of liquid entering the pipe.
$T_{initial}$	[ºC]	The initial temperature of liquid in the pipe.
T_o	[ºC]	The temperature of liquid exiting the pipe.
$\overline{T}_f$	[ºC]	The average temperature of liquid in the pipe at the end of a given time step.
UA	[kJ/hr]	The overall energy loss rate from the pipe.
ΔE	[kJ]	The change in internal energy of the pipe since the beginning of the simulation.
Δt	[hrs]	The simulation time step
j, k	[-]	Subscripts used to denote liquid segments.
R_{inside}	[hr.ºC/kJ]	The thermal resistance of the liquid / pipe wall boundary
R_{pipe}	[hr.ºC/kJ]	The thermal resistance of the pipe wall
R_{insul}	[hr.ºC/kJ]	The thermal resistance of the insulation layer
$R_{outside}$	[hr.ºC/kJ]	The thermal resistance of the insulation / ambient boundary
h_{inside}	[kJ/hr.m^2.ºC]	The pipe inside convection coefficient.
$h_{outside}$	[kJ/hr.m^2.ºC]	The pipe outside convection coefficient.
A_{inside}	[m^2]	The inside surface area of the pipe

$A_{outside}$	[m^2]	The outside surface area of the insulation layer.
Re	[-]	The Reynolds number for liquid flowing in the pipe.
Pr	[-]	The Prandlt number for liquid flowing in the pipe.
Nu	[-]	The Nusselt number for liquid flowing in the pipe.
$d_{pipe,i}$	[m]	The inside diameter of the pipe
$d_{pipe,o}$	[m]	The outside diameter of the pipe (also the inside diameter of the insulation layer)
$d_{insul,o}$	[m]	The outside diameter of the insulation layer.
L_{pipe}	[m]	The length of the pipe
μ_{liquid}	[kg/m.s]	The dynamic viscosity of the liquid
k_{liquid}	[kJ/hr.m.ºC]	The thermal conductivity of the liquid
k_{pipe}	[kJ/hr.m.ºC]	The thermal conductivity of the pipe material
k_{insul}	[kJ/hr.m.ºC]	The thermal conductivity of the insulation

Detailed Description

Error! Reference source not found. illustrates the plug flow concept at the heart of both Types 709 and 31. A pipe is initially filled with 3 fluid segments having temperatures T_1, T_2, and T_3, and X_1, X_2, and X_3. (Figure 1a). In one time period (Δt), a mass of fluid, $\dot{m}\Delta t$, enters the pipe, creating a new segment (Figure 1b). The existing profile is displaced such that the same quantity of fluid that enters the pipe also exits the pipe. The segments and/or fractions of segments that fall outside the pipe are removed from the profile (Figure 1c). The average outlet temperature is computed as the mass weighted average of leaving elements.

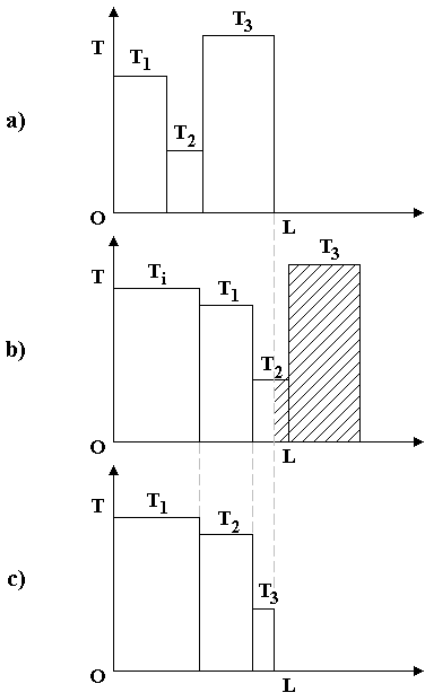


Figure 1: Pipe Fluid Flow

For the example of Figure 1, the average outlet temperature is given by equation 709.1

$$T_o = \frac{M_3\ T_3 + (\dot{m}\ \Delta t - M_3)T_2}{\dot{m}\ \Delta t} \qquad \text{(Eq.709.1)}$$

In general terms, the outlet temperature is given by equation 709.2

$$T_o = \frac{1}{\dot{m}\ \Delta t} \sum_{j=1}^{k-1} \left(M_j T_j + a\ M_k T_k \right) \qquad \text{(Eq.709.2)}$$

In which the coefficient a and the subscript k must satisfy the conditions shown in equation 709.3a and 709.3b respectively.

$$0 \le a \le 1 \qquad \text{(Eq.709.3a)}$$

$$\sum_{j=1}^{k-1} \left(M_j + a\ M_k \right) = \dot{m}\ \Delta t \qquad \text{(Eq.709.3b)}$$

Energy losses are considered for each element by solution of the following differential equation.

$$M_j\ Cp\ \frac{dT_j}{dt} = -(UA)_j\ \left(T_j - T_{env} \right) \qquad \text{(Eq.709.4)}$$

Whereas in Type31, the user is asked to specify the overall loss coefficient per unit area for the pipe, Type709 calculates this value based on user supplied physical parameters. The value of UA is given by equation 709.5

$$UA = \frac{1}{R_{inside} + R_{pipe} + R_{insul} + R_{outside}} \qquad \text{(Eq.709.5)}$$

The individual resistances are calculated as follows:

The inside resistance is based upon convection between the liquid flowing in the pipe and the pipe wall. The Reynolds number is given by the relation shown in equation 709.6

$$\mathrm{Re} = \frac{4\ \dot{m}}{\pi\ d_{pipe,i}\ L_{pipe}} \qquad \text{(Eq.709.6)}$$

The Prandlt number is given by 709.7

$$\mathrm{Pr} = \frac{\mu_{liquid}\ Cp_{liquid}}{k_{liquid}} \qquad \text{(Eq.709.7)}$$

And the Nusselt number is given by 709.8.

$$\begin{aligned} Nu &= 3.66 && for \quad \mathrm{Re} \le 2300 \\ Nu &= 0.23\ \mathrm{Re}^{0.8}\ \mathrm{Pr}^{0.25} && for \quad \mathrm{Re} > 2300 \end{aligned} \qquad \text{(Eq.709.8)}$$

Equations 709.6 through 709.8 are combined to give the inside resistance as shown in equation 709.9.

$$R_{inside} = \frac{1}{h_{inside}\ A_{inside}} = \frac{1}{\left(\frac{Nu\ k_{liquid}}{d_{pipe,i}}\right)\left(\pi\ d_{pipe,i}\ L_{pipe}\right)} \qquad \text{(Eq.709.9)}$$

The resistance of the pipe wall is given by equation 709.10

$$R_{pipe} = \frac{\ln\left(\frac{d_{pipe,o}}{d_{pipe,i}}\right)}{2\ \pi\ k_{pipe}\ L_{pipe}} \qquad \text{(Eq.709.10)}$$

The resistance of the pipe insulation is then calculated by equation 709.11

$$R_{insul} = \frac{\ln\left(\frac{d_{insul,o}}{d_{pipe,o}}\right)}{2\ \pi\ k_{insul}\ L_{pipe}} \qquad \text{(Eq.709.11)}$$

Lastly, the resistance of the outer convection is calculated using equation 709.12 in which $h_{outside}$ is a user provided input to the model.

$$R_{outside} = \frac{1}{h_{outside}\ A_{outside}} = \frac{1}{h_{outside}\left(\pi\ d_{insul,o}\ L_{pipe}\right)} \qquad \text{(Eq.709.12)}$$

For elements that enter or leave during a particular time step, only the duration of time within the pipe is considered. The total energy loss rate to the environment is the summation of the individual losses from each element given as

$$\dot{Q}_{env,j} = -(UA)_j\ \left(T_j - T_{env}\right) \qquad \text{(Eq.709.13)}$$

The change in internal energy of the pipe since the beginning of the simulation is:

$$\Delta E = M\ Cp\left(\overline{T}_f - T_{initial}\right) \qquad \text{(Eq.709.14)}$$