Sage Model Notes

HeatExchanger-JetImpingement.scfn

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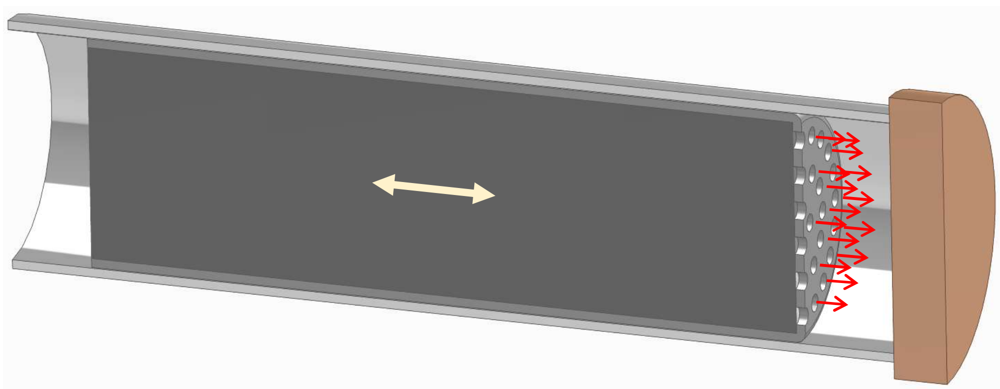
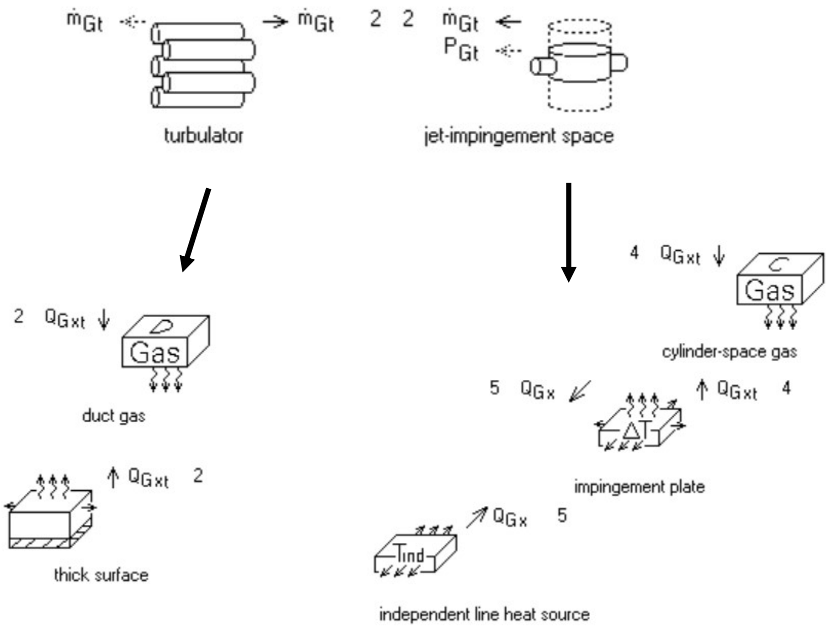
This sample models the heat transfer produced by fluid jets impinging on a solid wall surface. This type of heat exchanger is commonly used for small cryocoolers where the regenerator is housed inside a moving canister with a number of holes in the end through which gas flows from the regenerator into an expansion space. The gas emerges from the holes in the form of jets that impinge on the end surface of the expansion space, as shown in the cutaway rendering below of a cryocooler cold finger:



In Sage, the model comprises a *tube bundle* and *generic cylinder* renamed *turbulator*, for its role in creating turbulence, and *jet-impingement space*. Inside the turbulator are a *duct gas* and *thick surface*. The *thick surface* creates an adiabatic boundary condition because there is no heat transfer within the *turbulator* itself. Inside the *jet-impingement space* are a *cylinder-space gas*, *conductive surface* (renamed *impingement plate*) and *independent line heat source*.



This model makes use of the fact that Sage's *generic-cylinder* component and its associated *cylinder-space gas* component incorporate physics for modeling inflow-generated turbulence and its associated Nusselt-number correlation for gas-to-wall heat transfer. See the *Turbulence Models* and *Heat Exchangers* chapters in the Sage User's guide for details (Help | PDF Manual). According to Sage models, jet-impingement heat transfer can be very effective even for kW size heat exchangers, not just small cryocoolers.

To make this model fully functional it must be copied into another model containing a moving piston or displacer, based on one of the piston/cylinder components on the Composite page of the root-level component palette, with a P_{Gt} volume-displacement connector to attach to the one emerging from the *jet-impingement space*. Also required is a $\dot{m}_{Gt}$ gas flow connector to attach to the one emerging from the *turbulator*. Something like sample model SplitCycleCooler.scfn for example. That model implements a moving displacer shell with a regenerator inside providing both P_{Gt} and $\dot{m}_{Gt}$ connectors, with the gas emerging from the cold end of the regenerator flowing directly into the expansion space without any turbulent enhancement. That suffices for cooling powers on the order of 1 W but scaling that model up to higher power would benefit from jet-impingement heat transfer.

The *turbulator* component contains no user-defined variables. Built-in inputs `Dtube` (hole diameter) and `Ntube` (hole number) suffice to define its behavior. These can be selected for optimization within a larger model.

The *jet-impingement space* contains several of user-defined variables:

```
Inputs
  Dcyl              cylinder diameter (m)                       2.500E-02
  XampDesign        designed piston amplitude (m)               1.000E-02
  SurfEnhanceFac    impingement surface area factor (NonDim)    2.000E+00
  Rclearance        clearance volume ratio (NonDim)             2.500E-01

Outputs
  Acyl              cylinder end area                           4.909E-04
    0.25 * Pi * Sqr(Dcyl)
```

```
Recasts
  Swet = SurfEnhanceFac * Acyl
  Volume = (1 + Rclearance) * XampDesign * Acyl
  Length = 0.5*Dcyl
```

Within the context of a larger model `Dcyl` and `XampDesign` would likely be defined in higher-level components. `SurfEnhanceFac` defines the effective increase in cylinder-end surface area (where the *turbulator* jets impinge) relative to a flat surface. The cylinder end surface can have wetted-surface enhancements such as pin fins, drilled pockets, circumferential fins, grooves, etc. So long as the crevices or passages so formed are large enough for jet turbulence to penetrate without substantial decay they can increase overall heat transfer. Such details are beyond the scope of Sage. Setting an appropriate value of `SurEnhanceFac` will require experimental or CFD verification based in the detailed surface enhancement.

The impingement plate recasts the fin conduction length to the parent wall thickness input

```
  D = Twall
```

In the context of the above rendering the ultimate heat source is the exposed end of the copper plate (cold tip) and the heat flows through that plate to the inner surface exposed to the expansion space gas, thereby including the temperature drop through the plate within the model.