XML GUIDE FOR DUALSPHYSICS

MULTI-PHASE NON-NEWTONIAN FORMULATIONS

SPECIAL: NNPHASES

July 2020

DualSPHysics team

http://dual.sphysics.org

nnphases: Non-Newtonian multi-phase flows

A non-Newtonian multi-phase formulation is available in DualSPHysics v5.0. The rheology is based on the Herschel-Buckley-Papanastasiou (HBP) formulation capable of modelling a range of non-Newtonian fluids. A short description of the methodology is outlined below.

The HBP model is a generalised model for non-Newtonian fluids with four main parameters to characterise the non-linearity of the fluid:

- The viscosity of the fluid (or consistency)
- The yield stress of the fluid (τ_{yield})
- The flow index parameter (*n*)
- The exponential stress growth (*m*).

Further, a Bingham model (by means of a bi-viscosity model) is implemented (τ_{max}).

Two different formulations are implemented for the calculation of the velocity gradients in DualSPHysics v5.0:

- A finite differences approach operating in pairs of particles
- An SPH symmetric gradient approach.

The viscous forces are calculated either using the Morris (1997) operator or by using the full constitutive equation with an SPH formulation.

XML file: Special-nnphases

Definition of Phases

```
<special>
    <nnphases> %Defines non-newtonian phases parameters
        <phase mkfluid="0">
            <rhop value="1000" />
            <visco value="0.2" />
            <tau_yield value="0.0001" />
            <HBP_m value="100" />
            <HBP_n value="2" />
            <phasetype value="0" />
        </phase>
        <phase mkfluid="1">
            <rhop value="1000" />
            <visco value="0.1" />
            <tau_yield value="0.001" />
            <HBP_m value="10" />
            <HBP_n value="1" />
            <phasetype value="0" />
        </phase>
    </nnphases>
</special>
```

```
<!---Phase 1--->
<setmkfluid mk="0" />
<drawbox>
    <boxfill>solid</boxfill>
    <point x="0" y="0" z="0" />
    <size x="4" y="2" z="0.5" />
</drawbox>
<!---Phase 2--->
<setmkfluid mk="1" />
<drawbox>
    <boxfill>solid</boxfill>
    <point x="0" y="0" z="0.50" />
    <size x="1" y="2" z="0.25" />
</drawbox>
```

<Phase> … <Phase/> : Defines the phase fluid properties and the rheology parameters. The **mkfluid** should correspond to a fluid block created in <**mainlist/>** tags of the XML section as shown below:

XML file: Special-nnphases

Definition of properties

```
<phase mkfluid="0">
    <rhop value="1000" />
    <csound value="80" />
    <gamma value="7" />
    ...
    ...
    ...
</phase>
```

<rho /> : The tag defines the density of the phase of the specific **Mk** (not recommended for density ratios higher than two).

<csound /> : The tag defines the speed of sound for the phase to be used in the computation. Note that, the maximum speed of sound of all phases with be used in the time step CFL restriction whereas the phase specific speed of sound will be used in the equation of state (obtaining the pressure). Thus, the model is bounded by the maximum phase speed of sound. This parameter is *optional*, in this absence of this tag the speed of sound calculated by *gencase* will be used.

<gamma /> : The tag defines the polytropic index for the equation of state. This parameter is *optional*, in the absence of this tag the default polytropic index defined in <**constantsdef/**> tag will be used.

XML file: Special-nnphases

Definition of parameters

```
<phase mkfluid="0">
    ...
    <visco value="0.2" />
    <tau_yield value="0.0001" />
    <HBP_m value="100" />
    <HBP_n value="2" />
    <phasetype value="0" />
</phase>
```

The following tags define the parameters of the Herschel-Buckley-Papanastasiou (HBP) model based on the fluid properties.

<visco /> : The tag defines the kinematic viscosity (or consistency) of the phase.

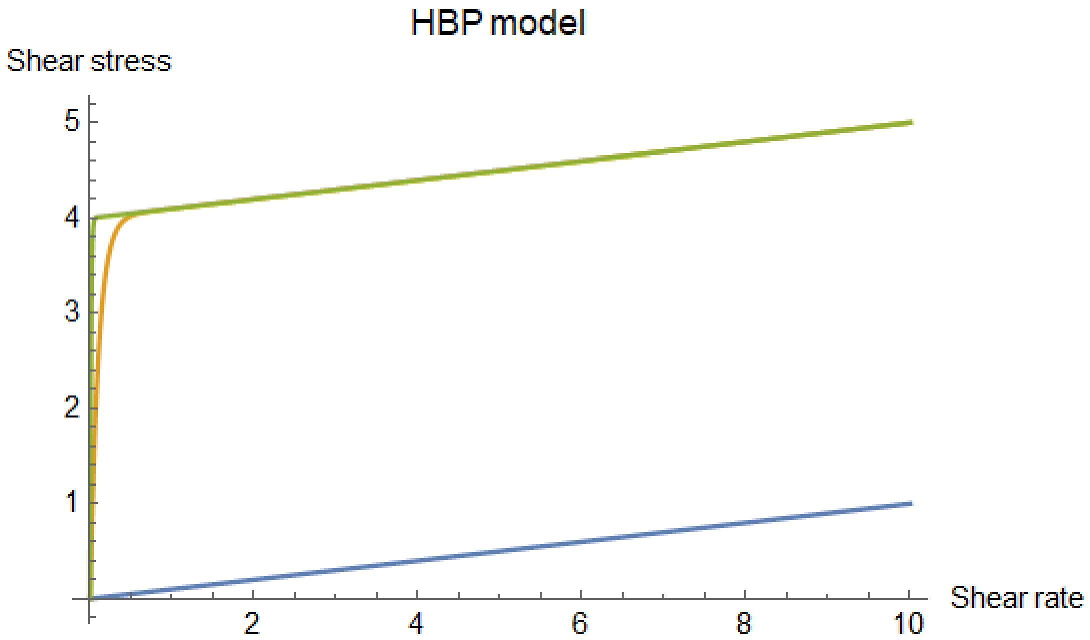
<tau_yield /> : The tag defines the specific yield stress of the material (τ/ρ) the fluid may experience before yielding.

<HBP_m /> : The tag defines the Papanastasiou exponential stress growth of the fluid. A value of zero reduces the yield stress to zero (Newtonian), a value of the order of ten to pseudo-Bingham and order of 100 to Bingham.

<HBP_m /> : The tag defines the Herschel-Buckley flow index. A value of one reduces the model to linear whereas a value smaller than one to shear thinning and greater that one to shear thickening fluid.

Definition of parameters

Herschel-Buckley-Papanastasiou (HBP) model fluid parameters

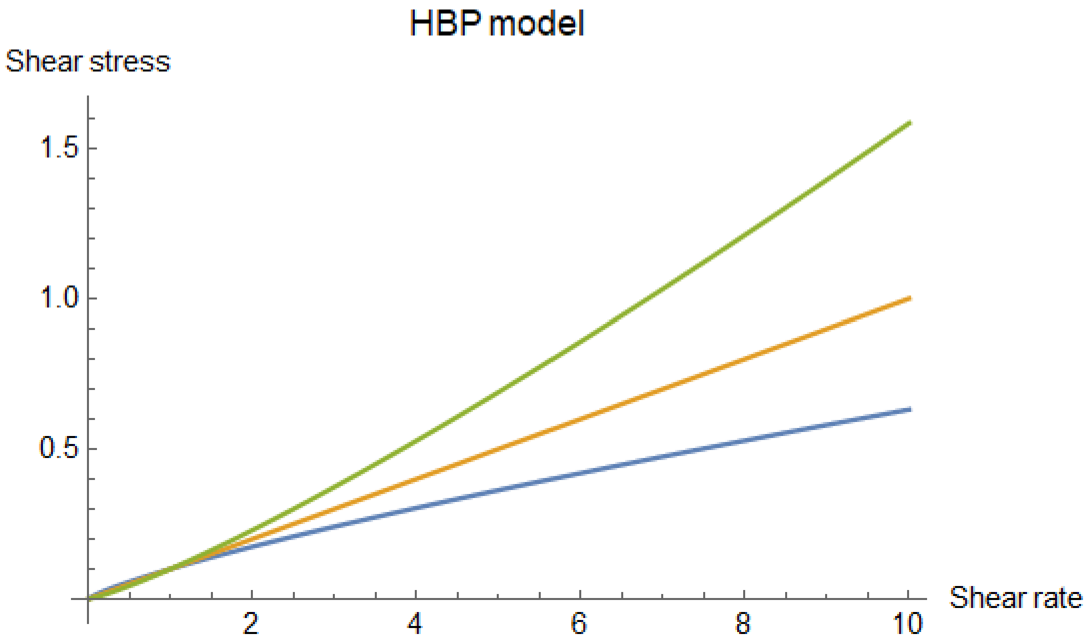


<HBP_m /> parameter: **m=0** **Newtonian** **m=10** **Power law** **m=100** **Bingham**

XML file: Special-nnphases

Definition of parameters

Herschel-Buckley-Papanastasiou (HBP) model fluid parameters



<HBP_m /> parameter:

n=0.8	n=1	n=2
Shear thinning	**Newtonian**	**Shear thickening**

XML file: Special-nnphases

Definition of parameters

```
<phase mkfluid="1">
    ...
    ...
    <tau_yield value="0.001" />
    <tau_max value="0.001" />
    <Bi_multi value="10.0" />
    ...
    ...
</phase>
```

The following tags define the parameters of the Bingham fluid implemented by a bi-viscosity model to avoid singularity and large viscosity values.

<tau_max /> : The tag defines the Bingham specific yield stress of the material (τ/ρ) the fluid may experience before yielding.

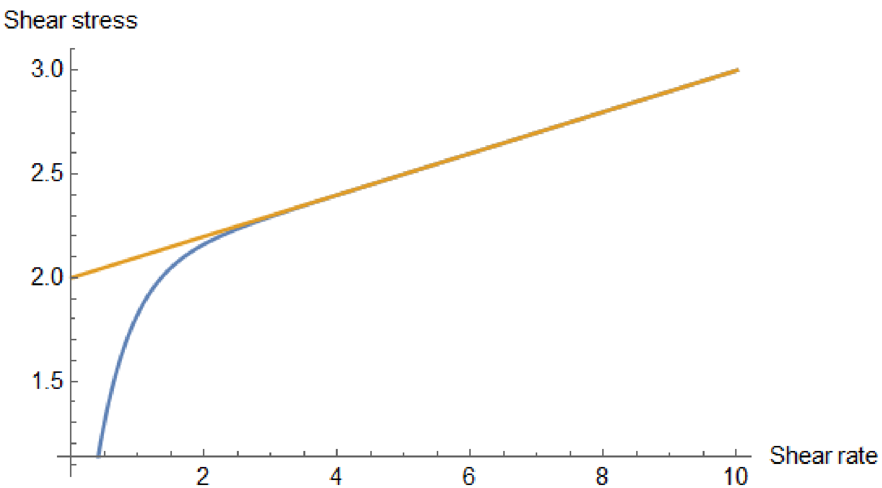
<Bi_multi /> : The tag defines the viscosity multiplier of a bi-viscosity model. This value multiplies the tau_max in the yielded region to avoid the singularity of the Bingham model.

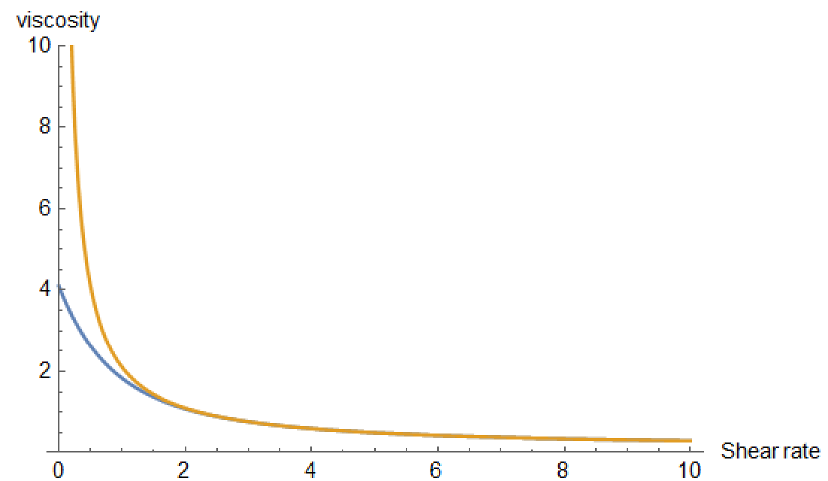
Note, these two values are *optional* and should be used only if a Bingham model (or bi-visocity) is required, *both tags must be present*. Further, these two tags override the Papanastasiou **<HBP_m/>** value (**HBP_m** = 0).

XML file: Special-nnphases

Definition of parameters

Herschel-Buckley-Papanastasiou and Bingham models





The Bingham model exhibits a discontinuity when the shear rate is zero and $v \rightarrow \infty$.
The Herschel-Buckley-Papanastasiou has a finite v value over the yielded region and at the origin.

XML file: Special-nnphases

Definition of solver

```
%Choice of reology treatment, velocity gradient calculation and viscosity treatment
<parameter key="RheologyTreatment" value="2" />
<parameter key="VelocityGradientType" value="1" "1:FDA, 2:SPH (default=1)" />
<parameter key="ViscoTreatment" value="3" "1:Artificial, 2:Laminar+SPS, 3:Constitutive eq." />
```

The following tags define the solver formulations to be used in the tag <**parameters/**> of the XML.

<**RheologyTreatment/**> : The tag defines the rheology treatment is used. In the beta version only option *2 Single and multi-phase* is allowed.

<**VelocityGradientType/**> : The tag defines which gradient formulation is used when calculating the velocity gradients.

<**ViscoTreatment/**> : The tag defines which formulation is used when calculating the viscous forces. Three choices are available, artificial viscosity (Newtonian only), laminar viscous operator by Morris (1997) and the SPH constitutive equation.

```
<parameter key="RelaxationDt" value="0.2" "(default=0.2)" />
```

<**RelaxationDt/**> : This tag defines a relaxation parameter for the viscous forces time step restriction in the form of $\lambda = \frac{1}{RelaxationDt}$.