Fluid Codes and Heavy Impurities

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% Present status of impurity fluid codes available at JET% Issues for inclusions of heavy species

1¹/₂-D Fluid Transport Codes

Assumptions:

- Axisymmetry
- The magnetic flux surfaces define the geometry
- Transport is analysed in the radial coordinate ρ, perpendicular to the FS
- The non-circularity is taken into account through "geometry factors" (V',



$$\begin{array}{l} 1\frac{1}{2}\text{-}D \text{ Fluid Transport Codes}\\ \frac{1}{V}\frac{\partial}{\partial t}\left(n_{i,z}V'\right) + \frac{1}{V'}\frac{\partial}{\partial \rho}\left(V'\left\langle\Gamma_{i,z}^{\rho}\right\rangle\right) = Q_{i,z} - S_{i,z}\\ Z \text{ coupled eq.ns}\\ \langle\cdots\rangle \quad \text{represents the FS average of the flux: } \Gamma_{i,z} = -D_{i,z}\nabla n_{i,z} + v_{i,z}n_{i,z}\\ \left\langle\Gamma_{i,z}^{\rho}\right\rangle = \left\langle\Gamma_{i,z}\cdot\nabla\rho\right\rangle = -D_{i,z}\left\langle\left|\nabla\rho\right|^{2}\right\rangle\frac{\partial n_{i,z}}{\partial\rho} + v_{i,z}\left\langle\left|\nabla\rho\right|\right\rangle n_{i,z}\end{array}$$

 $Q_{i,z}$ is the source term for each charge *z* of the impurity i due to ionisation from *z*-1 and recombination from *z*+1

 $S_{i,z}$ is the sink term due to ionisation to z+1 and recombination to z-1

The atomic physics in source and sink terms is from ADAS.

Impurity Experimental Data Available

- Spectroscopic lines : time evolution
- CX: fully stripped ion-profiles n(ρ,t) for low-Z impurities: (He), C, Ne, Ar
- Total Power (bolometry) and Filtered Power (SXR): multiple-lines-of-sight --> tomography

Impurity Transport Analysis

• Inputting $D_{i,z}(
ho)$ and $v_{i,z}(
ho)$,

the coupled equations are advanced in time

$$n_{i,z}(\rho,t)$$
 for each $z=1,\ldots,Z$

All relevant quantities can be derived: I-o-s of spectroscopic lines, SXR, ..., making use of ADAS data

Experimental and simulated data are compared

Impurity Analysis at JET (core)

• Fully Interpretive analysis: for low-Z impurities

Source-free : $0.1 - 0.2 \le \rho \le 0.6 - 0.8$

CX profiles of fully stripped He, C, Ne

Transients

At each
$$\rho$$
: $\Gamma_i / n_i = -D^* \frac{\nabla n_i}{n_i} + v^*$

Linear regression of Γ_i / n_i against $\sqrt{n_i} / n_i$

$$\longrightarrow$$
 get D*(ρ) & v*(ρ)

Impurity Analysis at JET (core)

• For heavier impurities and T:

experimental $n_{i,z}(\rho,t)$ are **not** measured directly BUT

•Multi-channel SXR (high-Z) or Neutron Yield (T) can be used

Injected trace impurity *i* produces an increase in SXR emissivity, simulated as:

$$\Delta \varepsilon_i(\rho, t) = n_e(\rho, t) \cdot \sum_z n_{i,z}((\rho, t), D, v) \cdot P_{i,z}(T_e, n_e, filter)$$

D & v are optimised until best match between simulated and experimental data

Impurity Analysis at JET (core)

- Predictive-Interpretive analysis:
 - UTC

version of SANCO stand-alone

simulated data optimised against experimental data optimization technique to get D & v

mainly transient phenomena of traces (T, Ne, Ar, Ni)

- STRAHL (Garching)
- Mattioli (Cadarache & Padova)

(atomic data collected by M. Mattioli)

Impurity Analysis at JET

• Fully Predictive analysis (modelling): JAMS

version of SANCO integrated in the code chain JAMS

D & v: from theoretical models

- neoclassical package NCLASS;
- Weiland model, with diagonal and off-diagonal elements of transport matrix;
 - ... (other models) ...
- + combination of models

or

• predictive-interpretive mode (transport given from file)

Beyond the core into SOL

JAMS:

SANCO is integrated in the modular code **COCONUT**, combining

- a Monte-Carlo code (NIMBUS -> EIRENE) for the <u>neutral</u> sources,
- the 2-D scrape-off layer code EDGE2D
- the core energy and particle transport code JETTO,

using SANCO for the impurities

The edge and the core are joined at the separatrix (or just inside)

JAMS: Integrated approach - COCONUT



In a COCONUT run, EDGE2D provides self-consistent b.c. for the core **JETTO-SANCO can be run without EDGE2D/NIMBUS**

EDGE2D-(NIMBUS)EIRENE

- The conservation equations are written in the poloidal plane, with ρ labelling the FS and θ the poloidal coordinate (fully 2D)
- The MonteCarlo module (NIMBUS being replaced with EIRENE) is used to evaluate the density, temperature and velocity profiles of the <u>neutral</u> species
- Parallel transport (along θ) is <u>classical</u> (Braginskii/21-moment approx)

2 D
$$\rightarrow$$
 much longer CPU time

Heavy Impurities and Bundles

•Tungsten wall in ITER: simulations of W ingress from the wall into the SOL and then to the core

• CPU time needed increases with Z -> EDGE2D simulations with W are far too heavy in CPU and there are numerical stability issues (too many species with negligible density).

• BUNDLED STATES: from the numerical point of view the number of equations is greatly reduced and makes EDGE2D runs possible.

BUNDLED STATES: issues

- Neutrals are of different nature than ions: need to be kept separate → cannot be bundled with low charged ion states
- 'Optimum' bundling scheme?
 - Likely to depend on: T_e , ne, ∇T_e , D, v,... region of the plasma (core, edge)

BUNDLED STATES: issues (cont'd)

- How to 'optimise' bundling scheme:
- SANCO: high-Z impurities (Ni, Mo, W)
 - full set of ionised states and compare with various numbers of bundles, various bundling schemes,

Perform scans in Te, D and v

- Core-Edge: different bundling schemes?
- Figure of merit?