A.1 RELEASE 2023.10

We dedicate this OPM 2023.10 release to our colleague and friend David Baxendale. David passed away in late June 2023 after a short severe illness. Our thoughts are with his wife and son. The OPM community is very thankful for all his contributions to OPM and the fruitful discussions with him about issues with and advancements of the simulator.

David started contributing to OPM in 2016 as *OPMUSER* on github and continued his good work until his very last days. We owe the OPM Reference manual to him. He started this heroic effort in 2017 and it has now thousands of pages. We, his colleagues and friends, are and will be surely missing him with his reservoir engineering expertise and know-how, his enthusiasm, and humor.

The 2023.10 release consists of some new features and various improvements and bug fixes. Our main target was to support more keywords used for relevant field and reduction of differences between OPM flow and the commercial simulator. These improvements include

- Added support for temperature (THERMAL) plus salt precipitation (PRECSALT) modeling in gas-water-brine (GAS-WATER-BRINE) systems
- Added support for modelling dissolved gas in water (DISGASW) and vaporized water in the gas phase (VAPWAT) in the thermal-gas-water simulator
- Support for modeling FOAM combined with SOLVENT
- partial support for WAGHYSTR keyword (Water-Alternating-Gas hysteresis)
- Improvements to many user-facing error messages.
- More graceful exits for problems in parallel runs.
- Temperature is output if requested via RPTRST
- Added support for WBP, WBP4, WBP5 and WBP9 in the SUMMARY section to output well block averaged pressures for open completions
- Added support for initializing constant flux aquifers from a restart
- Added support for WBP, WBP4, WBP5 and WBP9 in the SUMMARY section to output well block averaged pressures for open completions
- Faster two-point flux-approximation introduced in the last release is now also used for linearizing gas-oil cases with energy (with diffusion) and gas-oil diffusion

A.1.1 NEW AND DEPRECATED COMMAND LINE OPTIONS

The major command line changes made for this release are summarized in Table 1

No.	Variable Name	Description	Default
OPM Flow 2023-11 New And Deprecated Command Line Options			
1	--enable-opm-rst-file	Include OPM-specific keywords in the ECL restart file to enable restart of OPM simulators from these files. The behavior of the simulator has been modified so that thermal data will still be output if TEMP or THERMAL are set in the input deck even if this option is set to false.	false
2	--num-pressure-points-equil	Added developer parameter (invisible to end users) to change the number of pressure table points (x) used in equilibration (#4718).	???
3	--local-domain-ordering-measure	Added parameter to specified the domain ordering measure as either residual or pressure (#4738).	residual ???
4	--local-well-solve-control-switching	Added trigger to enable (true) or disable (false) well control/status switching during local well equation solves (#4895).	false
5	--nldd-num-initial-newton-iter	Added option to specify number of global non-linear (Newton) iterations performed by the NLDD solver before starting the local non-linear iterations. The default value of 1 preserves the current behavior (#4922).	1

No.	Variable Name	Description	Default
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Notes:

1) Cells colored in green in the "No." column indicate a new command line option or a change to an existing option for this release.

2) Cells colored in gray in the "No." column indicate a new command line option or a change to an existing option for this release, but is only available for the *flow_black-oil simulator*, that is it is <u>not available</u> for the main simulator, *flow*.

3) Cells colored in orange in the "No." column indicate the command line option is available but is now "hidden" from the main help listing, *--help*. These options can be listed using the *--help-all* command line option, that lists all the command line options included in the release, including experimental, obsolete, hidden and deprecated options.

4) Cells colored in red in the "No." column indicate a deprecated command line option for this release.

Table 1: OPM Flow 2023-11 New and Deprecated Command Line Options

A.1.2 NEW FEATURES

In addition to the above the following new features have been added to the simulator:

1) When the general well specification data is defined by the WELSPECS keyword in the SCHEDULE section the well can now be assigned directly to the FIELD group in item 2 GRPNAME (#3485, #4608). Previously there was a restriction preventing wells from being parented directly to FIELD. Although wells are now allowed to be parented directly to FIELD, this is discouraged and a warning message will be issued. Mixing wells and groups as children of a single group is still forbidden.

2) Added support for dissolved gas in water (DISGASW) in the gas-water simulator with salt precipitation (PRECSALT) and vaporized water in the gas phase (VAPWAT) (#4623). However, input of gas solubility in water is not currently supported so this option is only useful in combination with CO2STORE .

3) Added support for modelling dissolved gas in water (DISGASW) and vaporized water in the gas phase (VAPWAT) in the thermal-gas-water simulator (#4661).

4) Added support for temperature (THERMAL) plus salt precipitation (PRECSALT) modeling in gas-water-brine (GAS-WATER-BRINE) systems as specified in the RUNSPEC section (#4650). This has to date only been tested in combination with CO2STORE. Note that generally, if the PRECSALT keyword has been activated in the input deck then the VAPWAT keyword should also be activated.

5) Added support for modeling foam (FOAM) plus solvent (SOLVENT) in the simulator [foam added to solvent model]. (#4654,#3523,#805). Also allow for water as transport phase in the well model.

6) Added support for updating the oil vaporisation parameters (VAPPARS) in the SCHEDULE section (#4677).

7) Added support for WVFPDP in the SCHEDULE section (#4620,#3504). The WVFPDP keyword modifies a well's Bottom-Hole Pressure ("BHP") estimated by the simulator by interpolation of the Vertical Flow Performance ("VFP") tables.

8) Added support for GCONPROD item 7 ACTION equal to NONE in the SCHEDULE section, which specifies that no action is to be taken if the oil, water, gas or liquid rate constraints are violated. Previously only the RATE option was supported by the simulator.

9) Added partial support for WAGHYSTR keyword in the PROPS section (#4710,#3542). This keyword defines the parameters for the Water-Alternating-Gas ("WAG") hysteresis option, when the hysteresis option has been activated by the HYSTER variable on the SATOPTS keyword in the RUNSPEC section. Only gas phase hysteresis is currently supported by the WAGHYSTR keyword. The residual oil modification fraction, which would only be active when the STONE1 three-phase oil relative permeability model is used, is not currently supported.

10) Support added for PPCWMAX to limit the maximum capillary pressure scaling when initialising the model using SWATINIT, and the option to modify the connate water saturation to match the input water saturation if the capillary pressure is exceeded (#4707,#3570).

11) Added support for WINJMULT in the SCHEDULE section to define pressure dependent injectivity multipliers for injection wells and can be used to approximate the change in injectivity due to hydraulic fracturing (#4686).

12) Added support for WBP, WBP4, WBP5 and WBP9 in the SUMMARY section to output well block averaged pressures for open completions (#4695,#4694,#4693).

13) Added partial support for WPAVE and WWPAVE defining the method and parameters for calculating a well's block average pressures for either all wells or specific wells (#4695,#4694,#4693). Calculation of block averages pressures is currently only supported for OPEN completions (not for ALL completions) as specified in WPAVE item 4 and WWPAVE item 5.

14) Aquifer keywords have been enabled when H2STORE is specified in the RUNSPEC section with brine modelled by the OIL phase (#4791). This is similar to the behaviour when CO2STORE is specified.

15) User defined arguments (UDA) have been enabled for the WINJFCNC keyword item 2 (FCONCPPM) the injection concentration parameter (#4763,#3614). The WINJDAM, WINJFCNC and WINJCLN keywords are used to model formation damage due to filtration of particles during water injection.

16) Added partial support for GRUPNET (#4760,#3609), which defines the standard group network parameters used to model the flow and pressure behaviour within the network. GRUPNET item 5

SUBSEAMANIFOLD/OPTION1 equals NO only is supported; item 6 LIFTGAS/OPTION2 equals NO only is supported; item 7 ALQ-DEN/OPTION3 equals NONE only is supported.

17) Added support for GRUPNET item 6 LIFTGAS equals FLO (#4819,#3651). Item 6 of GRUPNET now supports NO and FLO but not ALQ.

18) Added partial support for GECON (#4819,#3657). Item 7 WORKOVER only supports NONE i.e. workover procedures are not currently implemented. Item 8 ENDRUN only supports NO – end run not currently implemented. Item 9 MXWELLS is not supported and must be defaulted.

19) Support has been added for the CSKIN keyword in the SCHEDULE section to modify the connection skin factor (#4871,#3681).

20) Support for WSF and GSF keywords in the PROPS section has been added for H2STORE runs (as for CO2STORE) (#4528). The WSF and GSF keywords define the water relative permeability data versus water saturation tables and the gas relative permeability data versus gas saturation tables for when gas and water are only present in the input deck. These keywords can only be used with either the CO2STORE or H2STORE models.

21) Support has been added for setting the WGRUPCON keyword Item 2 STATUS in the SCHEDULE section equal to NO (#4575).

22) Support has been added for setting the PINCH item 2 PINCHOPT parameter equal to NOGAP in the GRID section. This parameter is now fully supported by the simulator. Previously only the default GAP option was supported (#4603).

23) Added support for initializing constant flux aquifers from a restart (#4520,#4519). In particular, form constant flux aquifer objects from the restart step's collection if available and properly initialize their total produced volume. To that end also calculate the local face area fraction for the aquifer's connections which handles the constant flux aquifer from the restart file in the case that the aquifer's connections are split across multiple MPI ranks.

24) Added support for gas-water-solvent systems (#4568,#4548).

25) Added partial support for setting items 11, 12 and 13 of GCONPROD in the SCHEDULE section: ACTWAT, ACTGAS and ACTLIQ respectively define the action to be taken if the water rate (WRAT), gas rate (GRAT) and liquid rate (LRAT) constraints defined by GCONPROD are violated. Supported options are now NONE or RATE. Options CON, +CON, WELL, and PLUG are not currently supported (#4748).

26) The option has been added to allow well control or well status to be updated during the iteration process during local solve for the well equations. In this way the converged well is given the correct control/status for the current reservoir state. A command line argument –local-well-solve-control-switching=true has been added to trigger the use of the function (this is false by default).

A.1.3 IMPROVEMENTS

Improvements include:

1) The correct version of flow is now selected for two-phase gas-water systems with either water vaporized in the gas phase (VAPWAT) and/or gas dissolved in the water phase (DISGASW) as defined in the RUNSPEC section (#4592). Previously the wrong version of flow was selected for gas-water systems with water vaporized in the gas phase (but no gas dissolved in the water phase).

2) The boundary conditions keyword BC has been deprecated and been split into two parts: BCCON in the GRID section where the block indices and direction are set, and BCPROP in the SCHEDULE section where the type and value of the boundary condition are set (#3482, #802 and #949).

3) The maximum number of allowable EQLNUM regions has been increased from 255 to 65525 (#4726).

4) A stricter convergence tolerance has been imposed on standard (not multi-segment) wells with a zero rate target. This change improves the results of a reported case with zero reservoir volume rate (RESV) control and potentially improves the material balance of the whole system (#4572).

5) When testing a gas lift well under THP control, if the well does not converge with the maximum artificial lift quantity (ALQ) then the simulator will now try to reduce ALQ in increments to check if the well equations converge with a smaller ALQ (#4579).

6) The bisection algorithm has been updated to keep track of the size of its search interval. The algorithm will now stop iterating if the minimum interval size is reached (#4617).

7) The simulator has been modified to ensure that THP constraints are only applied to prediction wells and not history match wells (#4615).

8) The simulator has been updated to avoid requesting the ALQ value for injectors, the ALQ value is only requested for producers (#4648).

9) The simulator has been modified to output temperature information to the restart file if TEMP is specified in the RPTRST keyword or if THERMAL is set in the RUNSPEC section even if the command line option *--enable-opm-rst-file=false* is set (#4646). The command line option *--enable-opm-rst-file* is a Boolean value that controls the output of OPM specific data sets to the commercial simulator's restart file to enable restart of OPM Flow runs by OPM Flow (*true*), or not to output the data (*false*).

10) Update the calculation of immobile gas saturation to take into the account trapped saturation calculated when the hysteresis model is used (#4642 and #3517). The hysteresis model is activated by the specifying the HYSTER parameter of the SATOPTS keyword in the RUNSPEC section

11) An error message will now be generated if invalid region numbers SATNUM, PVTNUM, IMBNUM or EQLNUM are input (#4705). Valid region numbers are positive integers less than or equal to the maximum number of regions specified in the RUNSPEC section.

12) If vaporised water (VAPWAT) is present in the model but the initial equilibrium vaporized water in gas ratio (RVW) for an equilibration region is not explicitly defined by a value versus depth table (RVWVD), and the datum depth is not at either the gas-oil contact (if oil is present) or the gas-water contact (if oil is not present) then the values of RVW will be initialised to zero (#4647 and #4688). This is to make it easier to use VAPWAT in CO2STORE cases .

13) The mass balance limit (XXXMBE) from the keyword TUNING is now used if it is explicitly specified (not defaulted) and the command line argument --enable-tuning=true is used (#4621,#3522).

14) The simulator now gives a more informative error message if the input grid has no active cells at all. Often this points to an error in the input data and this change might help in finding the problem (#4735).

15) A more user-friendly error message is now reported when the time step is cut too often/much. (#4746).

16) Perform a more graceful exit instead of MPI_Abort for expected exceptions in parallel runs. Instead of unconditionally issuing MPI_Abort if we encounter a fatal exception, we try to test whether all processes have experienced this exception and if this is the case just terminate normally with an exit code that signals an error. We still use MPI_Abort if not all processes get an exception as this is the only way to ensure that the program aborts (#4750). This approach also works around issues in some MPI implementations that might not correctly return the error.

17) The restriction on the length of the next timestep following an event will now be applied following production or injection updates (WCONPROD, WCONINJE keywords) (#4781). The maximum length of the next timestep following an event can be set using either the TUNING keyword item 10 (TMAXWC) with the command line argument *--enable-tuning=true*, or by using the command line argument *--time-step-after-event-in-days=x* (where x is the number of days).

18) Hydrostatic and acceleration pressure losses have been included for well segments representing an inflow control device (ICD) (#4824). Valves may be placed in long segments with significant depth differences (for example, at branch inlets), where the hydrostatic contribution in particular may be significant.

19) An error message is now reported if a negative oil or water saturation is passed to the RV and RVW initialization routine (#4675).

20) When approximately zero well rates are encountered during iterations (pre-convergence), gas/water fractions become highly inaccurate which in turn may lead to the solver getting stuck or the well getting shut prematurely. The code has been updated to switch to explicit VFP table lookup whenever the rate drops below the lowest value in the table. The logic around explicit lookup is also updated so that this approach also works for just opened wells (#4669).

21) Information about linear system sizes is now output to the DBG file (#4734 and #4754).

22) The max size of the next time step is only used when specified in TUNING or NEXTSTEP (#4660).

23) For stopped or zero-rate-target wells the *alternative_well_rate_init* procedure previously returned unscaled well-rates resulting from a zero-bhp condition. This could lead to convergence failures for network balancing since the initialized rates could be off by orders of magnitude. The code now skips

this procedure for stopped or zero-rate-target wells reducing the risk of convergence failures (#4817).

24) The two-point flux-approximation (TPFA) has been added as a linearizer for gas-oil cases with energy (with diffusion) and gas-oil diffusion (#4825 and #4816). All energy cases now have diffusion enabled.

25) Added RESTART file output for the geomechanical module (#4803 and #4588).

26) Relaxation factors slightly outside the interval [0, 1] in the standard well model are reset to the interval limits, while keeping the assertion for factors further outside the interval to possibly pick up failure cases (#4862).

27) Connections between reservoir cells and numerical aquifer cells, or between numerical aquifer cells when multiple such cells define a single numerical aquifer, are now always treated as NNCs for output purposes (#4821).

28) Regional transmissibility multipliers such as those entered in the MULTREGT keyword are now applied to explicit input non-neighbor connections (NNC). This now implements all know connection behaviors for inter-region connections. Multipliers internal to region in MULTREGT are not yet supported (#4822 and #4821).

29) The name of the missing OPM restart file is reported in the error message when it cannot be located (#4870).

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Error locating serialized restart file PATH/FILENAME.OPMRST
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30) Added PRT file output when group economic criteria for production groups GECON is activated (#4866).

31) Reduced repetitive output of network information when running in parallel (#4879).

32) The lower limit for bottom hole pressure (BHP) in Newton updates has been reduced slightly from 1 bar. This allows for cases that might have a defaulted BHP constraint of 1 bar (#4877).

33) The region set name matching algorithm has been changed to using unique prefixes. This enables the simulator to recognize that the region set name FIPUNI should match the user defined region name FIPUNIT (#4868).

34) Debug output sent to the DBG file is no longer also echoed to the console as well (#4955 and #4941).

35)

In addition, the following new SUMMARY keywords are now recognized as described by the comments in Table 2.

No.	Summary Keyword	Comment
1	WINJFVR, WINJFVT and WINJFC	Added support for SUMMARY keywords relating to filtration injection modelling (#4790, #3628 and #3626). Added injection well SUMMARY vectors for filtrate volume injection rate (volume rate), filtrate volume injection total (volume), and filtrate injection concentration (ppm).
2	CINJFVR, CINJFVT, CFCSKIN, CFCWIDTH, CFCPERM, CFCPORO, CFCRAD and CFCAOF	Added support for SUMMARY keywords relating to filtration injection modelling (#4790, #3628 and #3626). Added injection well connection SUMMARY vectors for filtrate volume injection rate (volume rate), filtrate volume injection total (volume), skin factor due to filtration (dimensionless), thickness of filter cake (Length), permeability of filter cake , porosity of filter cake (dimensionless, also potentially variable with compressibility), well bore radius used in the filtration modeling (Length), and well bore area of flow used in the filtration modeling (Area)
3	BFLOWI, BFLOWJ, and BFLOWK	Added support for SUMMARY vectors BFLOWI, BFLOWJ and BFLOWK to request block oil/gas/water flow rates at surface conditions (#4867,#3675,#827). This does not require FLOWS to be specified in RPTRST.
4	SDENx, SDENM and SMDEN	Added support for SUMMARY vectors to output fluid densities at the block and well segment levels (#4744, #3594 and #3593). Added well segment SUMMARY vectors for phase density of phase x (segment conditions), fluid mixture

		density without flowing fraction exponents, and fluid mixture density with flowing fraction exponents. Phase x is one of O (oil), G (gas), or W (water).
5	BxDEN and BDENx	Added support for SUMMARY vectors to output fluid densities at the block and well segment levels (#4744, #3594 and #3593). Added block SUMMARY vectors for phase density of phase x. Phase x is one of O (oil), G (gas), or W (water).
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Table 2: New SUMMARY Keywords for the 2023-11 Release

A.1.4 BUG FIXES

The following bug fixes and improvements have been incorporated into this release.

1) Fixed the issue of incorrectly using the gas-oil contact depth for initialization of vaporized water (RVW) in the special case of a two-phase gas-water system. The gas-water contact depth is now used in this case (#4688 and #4647).

2) Fixed a bug in the group pressure maintenance (GPMAINT) code (#4664). Previously, if negative group pressure maintenance rates were calculated, they would first be used to incorrectly update the GPMAINT error integral, before the rates were later set to zero. Now the simulator only calculates rates for injectors if the pressure is below the regional pressure target (or for producers if the pressure is above the regional pressure target).

3) Bug fixes related to the handling of gas dissolved in water ratio (RSW) and water vaporized in gas ratio (RVW) in the standard well model (#4591).

4) If the data file contains the CPR keyword then the "CPR" preconditioner should be used unless it is overridden by a command line argument. Previously this was incorrectly overridden by the command line argument *–linear-solver-max-iter* , the correct command line argument *–linear-solver* is now used (#4700).

5) The user is now able to specify any number of threads, this prevents only one thread being used on some hardware where the number of processors would always be reported as one when using MPI and OpenMP (irrespective of the actual number). The behaviour is now: (a) if nothing is specified then 2 threads are used, (b) if OMP_NUM_THREADS is specified then this number is used regardless of the hardware and the command line argument *–threads-per-process* is ignored, and (c) if *–threads-per-process* is used and OPM_NUM_THREADS is not set then the number specified on the command line is used (#4709). There is check to make sure that the number of threads used by the linearizer is consistent (#811).

6) Fixed a bug related to indexing in the temperature boundary condition (#4761).

7) Gas dissolved in oil (RS) and oil vaporized in gas (RV) ratio initialized using value versus depth tables (RSVD, RVVD) should be limited by their respective saturated values. Fixed a bug where this limit was not applied at depths outside the range of depths in the RSVD or RVVD table (#4723).

8) For producers where all perforations have zero rates we approximate the perforation mixture fraction using the (inverse formation volume factor times mobility) ratio, and weight the perforation rates using the well transmissibility. The perforation mixture fraction was previously approximated using only the mobility ratio (#4681).

9) A case under investigation has some cells containing only oil and water (zero gas saturation), which have zero relative permeability (and mobility) for all the three phases. This caused problems in part of the code which assumed the total mobility was non-zero. For perforations having zero mobility for all the phases, the simulator now uses a small value to generate small perforation rates for those perforations, at the same time, the simulator can use these rates to recover the mixing ratios for those perforations (#4682 and #4681).

10) The correct formation volume factors are now used in the case of zero phases rates resulting in zero Rs, Rv, Rsw or Rvw. Previously the saturated formation volume factor was used in these cases (#4590).

11) The reservoir volume rate constraint (RESV) in GCONPROD was not honoured. This has been fixed (#4687).

12) Previously, in the case of zero threshold pressure and zero pressure difference, the code would set the pressure difference explicitly to zero. This would also set any derivatives to zero, which could disconnect the corresponding matrix rows. The code no longer sets the pressure difference to zero when not necessary (#4701).

13) Code has been updated to avoid dividing by zero when scaling the well rates in updateWellStateRates() (#4715 and #4649).

14) The code has been updated to avoid round off errors in phase saturations leading to the initialization of dissolved or vaporized fluid ratios (for example saturated RS) with saturated values instead of taking values from the input ratio versus depth table (for example RSVD) (#4720).

15) Code has been updated to avoid writing beyond array limits (#4753).

16) The well closure reason is now set to GROUP rather than ECONOMIC if a group economic constraint (GECON) is reached. This prevents the closed well being reopened with WTEST item 3 TEST equal to 'E' (#4854).

17) The simulator now sets the well THP to be zero in the WellState only if there is no VFP table associated with the well (#4932). Previously, this would be done if the well had no target THP or THP limit.

18) The code now checks whether LIFTOPT is active first to avoid unnecessarily running routines relating to gas lift optimization (#4956).

A.1.5 KNOWN ISSUES

1) OPM cannot be built with dune-fem version >=2.9. Please use a previous version.

2) More TBA