

APPENDIX B: OPM FLOW RELEASE HISTORY

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B.1 RELEASE 2022-10

The 2022-10 release consists of some new features and various improvements and bug fixes. Highlights for this release include: implementation of alternative boundary conditions to the model via the BC keyword in the SOLUTION section, directional relative permeability support, implementation of Killough's hysteresis model together with hysteresis modeling for both relative permeability and capillary pressure, incorporation of the Joule-Thomson effect in energy calculations, added partial support for NETBALAN keyword, added support for the LETI³²³ family of relative permeability and capillary pressure functions that can be used as a replacement for Corey³²⁴ type curves, and implemented the introduction of a new preconditioner to the linear solver by extending the existing Constrained Pressure Residual ("CPR") preconditioner to include wells via the `-linear-solver="CPRW"` command line option. In addition, more SUMMARY vectors are now supported, plus various enhancements to the RESTART file to improve compatibility and robustness. Significant work has also been conducted in fixing the number of reported bugs.

When building OPM Flow from source, the default is now be to compile a parallel binary if MPI is installed, this was already the default for the binary packages that were previously distributed. Secondly, support for building OPM Flow with the new current version of DUNE (2.9) has been added.

New and Deprecated Command Line Options

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

OPM Flow 2022-10 New And Deprecated Command Line Options			
No.	Variable Name	Description	Default
1	<code>--linear-solver</code>	A defined quoted character string that sets the configuration of the solver, valid values are: <ol style="list-style-type: none"> 1) ilu0 (default), 2) cpr (an alias for <code>cpr_trueimpes</code>)³²⁵ ³²⁶ and ³²⁷ 3) <code>cpr_quasiimpes</code>, 4) <code>cpr_trueimpes</code>, 5) <code>cprw</code>, 6) <code>amg</code>,³²⁸ or 7) a file name that has the extension ".json", that contains the linear solver configuration parameters. Option (5) extends the existing Constrained Pressure Residual ("CPR") preconditioner to include wells.	"ilu0"

³²³ Lomeland F., Ebeltoft E. and Thomas W.H., 2005. A New Versatile Relative Permeability Correlation. Paper SCA2005-32 presented at the International Symposium of the Society of Core Analysts held in Toronto, Canada, 21-25 August, 2005.

³²⁴ Corey, A.T.: "The Interrelation Between gas and Oil Relative Permeabilities", *Production Mon.*, 19. 38. (1954).

³²⁵ Wallis, J. R., Little, T. E., and Nolen, J. S.: "Constrained Residual Acceleration of Conjugate Residual Methods," paper SPE 13536 presented at the SPE Reservoir Simulation Symposium, Dallas, Texas, USA (February 10-13, 1985).

³²⁶ R. Scheichl, M. Roland, J. Wendebourg, Decoupling and block preconditioning for sedimentary basin simulations, *Computational Geosciences* 7 (2003) 295-318.

³²⁷ Klemetsdal, Ø.S., Møyner, O. & Lie, KA. Accelerating multiscale simulation of complex geomodels by use of dynamically adapted basis functions. *Comput Geosci* 24, 459–476 (2020). <https://doi.org/10.1007/s10596-019-9827-z>.

³²⁸ M. Blatt, A parallel algebraic multigrid method for elliptic problems with highly discontinuous coefficients, Ph.D. thesis, Ruprecht-Karls-Universität Heidelberg (2010).

OPM Flow 2022-10 New And Deprecated Command Line Options			
No.	Variable Name	Description	Default
		<p>For option (6) one enters a character string enclosed in quotes that defines the filename of a JSON configuration file for the flexible linear solver system. In this case the file extension should be 'json'.</p> <p>Note that the *.PRT file contains the "Property tree for the linear solver" listing, which is the JSON specification of the current case, and can be used as a guide to configure a user specific linear solver JSON file.</p> <p>See #4125.</p>	
2	--linsolver	Renamed to --linear-solver See #4125 .	"ilu0"
3	--linear-solver-verbosity	<p>A positive integer value that defines the output from linear solver:</p> <ul style="list-style-type: none"> 0 : No extra output, 1 : output per solution iteration, or 2 : output per iteration. <p>See #4130.</p>	0
4	--flow-linear-solver-verbosity	Renamed to --linear-solver-verbosity. See #4130 .	0
5	--linear-solver-require-full-sparsity-pattern	<p>A Boolean value set to true or false that if set to true the simulator will produce the full sparsity pattern for the linear solver.</p> <p>Removed, see #4243 and #4255.</p>	false
6	--min-strict-cnv-iter	<p>A positive integer that sets the minimum number of Newton iterations before relaxed tolerances are used for the CNV convergence criterion.</p> <p>See #4086.</p>	0
7	--max-strict-iter	Renamed to --min-strict-cnv-iter See #4086 .	0
8	--newton-max-iterations	<p>A positive integer that defines the maximum number of Newton iterations per time step used by the simulator.</p> <p>See #4234, #4185, #4223, #741 and #749.</p>	20
9	--flow-newton-max-iterations	Renamed to --newton-max-iterations. See #4234 , #4185 , #4223 and #741 .	
10	--newton-min-iterations	<p>A real positive integer that sets the minimum number of Newton iterations per time step used by the simulator.</p> <p>See #4141.</p>	1
11	--flow-newton-min-iterations	Renamed to --newton-min-iterations See #4141 .	

OPM Flow 2022-10 New And Deprecated Command Line Options			
No.	Variable Name	Description	Default
12	--cpr-reuse-interval	A positive integer that sets the reuse preconditioner interval. Used when --cpr-reuse-setup is set to 4, then the preconditioner will be fully recreated instead of reused every N linear solve, where N is this parameter.	10
13	--regularization-factor	A real positive value that defines the "regularization factor" for wells. Previously, --regularization-factor-msw was applied to only multi-segment wells, and is now replaced by this new variable for all well types.	100
14	--relaxed-pressure-tol-msw	A real positive value that sets the relaxation tolerance for the multi-segment well <u>pressure</u> solution in Pascals.	10000
15	--relaxed-well-flow-tol	A real positive value that sets the relaxation tolerance for the well flow residual in reservoir cubic metres (rm ³).	0.001
16	--shut-unsolvable-wells	A Boolean value that determines if the simulator should shut unsolvable wells (true), or not (false).	true
17	--vtk-write-diffusion-coefficients	A Boolean value that switches on (true) or off (false) the output of the molecular diffusion coefficients to the VTK ³²⁹ output files.	false
18	--vtk-write-effective-diffusion-coefficients	A Boolean value that switches on (true) or off (false) the output of the effective molecular diffusion coefficients for the medium to the VTK output files.	false
19	--vtk-write-tortuosities	A Boolean value that switches on (true) or off (false) the output of the tortuosity for each phase to the VTK output files.	false
<p>Notes:</p> <ol style="list-style-type: none"> 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 orange in the "No." column indicate the command line option is available but is now "hidden" from the main help listing, <i>-help</i>. These options can be listed using the <i>-help-all</i> command line option, that lists all the command line options included in the release, including experimental, obsolete, hidden and deprecated options. 3) Cells colored in red in the "No." column indicate a deprecated command line option for this release. 			

Table B.1: OPM Flow 2022-10 New and Deprecated Command Line Options

³²⁹ Virtualization ToolKit ("VTK") files used to visualize the 3D results from the model using ParaView, an open-source, multi-platform general purpose data analysis and visualization application (<https://www.paraview.org/overview/>). For the commercial simulator's compatible output files OPM's ResInsight 3D visualization package can be used instead and is specifically tailored for OPM Flow and the commercial simulator.

New Simulator Features and Improvements

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

- 1) Although the OPM Flow BC keyword in the SOLUTION section, that defines alternative boundary conditions to the model, has been available in previous releases, the keyword has not been documented in the manual. The keyword is now fully documented with the order of the parameters on the keyword changed from previous releases, in order to be more consistent with other BOX type keywords ([#3208](#) and [#3193](#)). Note that although the BC(TYPE) equal to DIRICHLET option did not make it into this release, it is expected to be in the next release.
- 2) Directional relative permeability assignment has now been implemented using the KRNUM keyword ([#532](#), [#4048](#), [#714](#), and [#3113](#)).
- 3) Added preliminary support for the Dune ALUGrid module, that provides an adaptive, load balancing, and unstructured implementation of the DUNE grid interface in two or three space dimensions supporting either simplices (triangle or tetrahedron) or cube elements ([#3972](#)).
- 4) Added support for Killough's hysteresis model, that is EHYSTR(HYSTMOD) equal to two and three. Together with hysteresis modeling for both relative permeability and capillary pressure, EHYSTR(HYSTOPT) equal to BOTH, PC and KR ([#3170](#), [#535](#) and [#4148](#)).
- 5) Implemented OPM Flow specific keywords for the Joule-Thomson coefficients for gas, oil and water phases, in preparation for incorporating the Joule-Thomson effect in models ([#3029](#)), as well as incorporating Joule-Thomson effect in energy calculations ([#500](#)). See keywords GASJT, OIL JT and WATJT in the PROPS section.
- 6) Add supported for the LET family of relative permeability and capillary pressure functions ([#3018](#), [#2917](#) and [#3756](#)).
- 7) Add support for MINPORV keyword, which is an alias for MINPV keyword. Also added additional checks, such that only one of MINPV and MINPORV can be active in the deck ([#3071](#) and [#3975](#)).
- 8) Implemented partial support for NETBALAN keyword in the SCHEDULE section, only the first three items are currently supported; however, work is ongoing to increase the functionality of the keyword ([#3954](#)).
- 9) Added a new preconditioner to the linear solver by extending the existing Constrained Pressure Residual ("CPR") preconditioner to include wells. The feature is activated via the command line parameter:

`--linear-solver=cprw`

and the feature should be considered experimental at this stage ([#3937](#) and [#3901](#)).

- 10) As per previous releases, the simulator has had an additional formulation to the standard polymer flooding model, known as the Polymer Molecular Weight Transport option, that uses the polymer molecular weight in calculating the polymer viscosity; however, the keywords associated with this model have not been documented. This has now been rectified in this release of the manual. The model is activated via the POLYMER and POLYMW keywords in the RUNSPEC section. The model does not account for non-Newtonian flow; the apparent viscosity is simply set equal to the zero-shear viscosity. Secondly, the standard polymer property data keywords: PLYROCK, PLYADS, PLYMAX, etc., are still required to fully describe the polymer fluid.
- 11) Added support for a simulation case to be run via Python and for dynamical changing the SCHEDULE section after the deck has been read from a file by a Python function ([#2833](#), [#2821](#), [#2781](#), [#3910](#), [#3031](#), [#3918](#), [#3037](#), and [#3040](#))
- 12) RESTART file additions and improvements:
 - a) Improved RESTART file compatibility with the commercial simulator by adding a "small rate threshold" when outputting the lift gas max supply rate limit and total gas production limit. The

- threshold renders the output discontinuous, but is needed for compatibility with the commercial simulator (#3039).
- b) Added support for loading the NETBALAN keyword parameters from a RESTART file to enable using the parameters in a restarted run (#3095). Added restart support for the NETBALAN keyword (#3095, #3103 and #3110).
 - c) Improved RESTART file compatibility when Network Balancing is being performed, as requested via the NETBALAN keyword in the SCHEDULE section. The improvement takes into account the minimum time step size for network balancing, NETBALAN(NTSTEP), as well as preserving negative balancing intervals exactly instead of replacing these values by zero (#3032).
 - d) Added the oil-water (PCOW) and oil-gas (PCOG) arrays to the restart file (#3904).
 - e) Added support for UDA variables for the WELTARG keyword in reading and writing the RESTART file (#3005).
 - f) Identified additional entries for WECON, WGRUPCON, and WVFPEXP keywords and fix an incorrect item attribution for the WTEST 'reason' parameter (#3021 and #3026). Added restart support for known well economic limits; however the following well economic limits are not currently supported: maximum gas-liquid ratio WECON(GLR), maximum temperature WECON(TEMP), maximum reservoir fluid flow rate WECON(RESV), and follow-on well WECON(WELOPEN) (#3095, #3103 and #3110).
 - g) Fixed an issue with the well list positions for individual wells (i.e., IWLS) not strictly increasing in the restart files (#3052).
 - h) The simulator can now restore the explicit THP control options (WVFPEXP keyword) from the RESTART file; thus, improving compatibility with the commercial simulator (#3114 and #3110).
- 13) Implemented a new and faster linearization approach specifically for the Two-Point Flux Approximation ("TPFA") method used in the simulator. The new version of the linearizer is used for one, two and three-phase black-oil simulations; whereas, the original linearizer is still used for extended models such as solvent, polymer etc. Testing indicates a significant speedup for the linearization phase, yielding an improvement in total run times of 6-8% or more, depending on the case. (#4017).
- 14) Added water evaporation into gas in combination with oil vaporization (#688). See also #3869 for water evaporation and salt participation.
- 15) Added water evaporation and salt participation for three-phase runs (oil, water and gas). Previously the simulator only supported gas-water models. Note that currently the simulator does not support:
- Water evaporation with multi-segment wells, only standard wells are supported.
 - Brine with multi-segment wells, only standard wells are supported.
 - Currently only Enumeration Initialization is supported via the RVW keyword.
- Work is ongoing to address these limitations by supporting multi-segment wells and a RVWD keyword to enable Equilibrium Initialization (#3869).
- 16) Previously for the Vaporized Model, only Enumeration Initialization was supported via the RVW keyword. This has been enhanced by adding support for Equilibrium Initialization with the support of the OPM Flow specific keyword, RVWVD, that allows for the initial vaporized water-gas ratio to be defined as a function of depth (#3107). In addition, the EQUIL keyword in the SOLUTION section was extended via EQUIL(EQLOPT6) parameter to allow for the RVWVD keyword to be used similarly as for the RVVD keyword (#4034).
- 17) Added support for WCONINJE(RSRVINJ) parameter that defines the injected dissolved gas ratio in injected oil or the vaporized oil ratio in injected gas (#2999 and #3879).

- 18) Implemented support for the WVFPXP keyword in the SCHEDULE section with the WVFPXP(IMPEXP) and WVFPXP(CONTROL) options (#4100 and #3837).

Improvements include:

- 19) Improved the date reporting for the ACTIONX keyword to avoid ambiguous dates. The simulator now reports dates in DD-MMM-YYYY, for example:

```
Action ACT-01 triggered at 02-Nov-2018 00:00:00 (report interval 0 to 1)
```

See #4003 for more information.

- 20) Previously whether or not an ACTIONX block was triggered the simulator would write out a message to the *.PRT file at every time step, which in some cases produced excessive number of messages, especially for non-triggered blocks (issue #4042). Now the simulator writes this information to the *.DBG file, and only writes message to the *.PRT file for triggered ACTIONX blocks. Additional improvements to the print output included sending the list of keywords to be executed when an ACTIONX block was triggered to the *.DBG file, instead of the *.PRT file (#4047 and #3112).
- 21) Improved how the ACTNUM property was processed by the simulator for all known grid types, which also fixed a special case that was not handled previously (#3063). In addition, improved the numerical aquifer connection logic to ensure that only active cells are connected to the aquifer (#3064).
- 22) Adapt drift compensation code to account for isolated cells and various other improvements (#3968 and #699).
- 23) Re-factored the analytical and numerical aquifer code to have a common base, and implemented the code in the black-oil aquifer model (#3994).
- 24) Previously, if there were any invalid aquifer connections, the simulator would print a warning message for every invalid connection. This would lead to an excessive number of associated warning messages printed to the terminal console, in one case over 50,000 messages were printed. Now only the first ten warning messages are printed to the console, and in addition the total number of invalid connections found. All warning messages are still printed to the print file (#3098 and #4007).
- 25) The AQUCT(AQUTAB) parameter defines the user entered Carter-Tracy AQUTAB table to be used for the aquifer. If the parameter is defaulted, then the simulator uses the Radial Flow, Constant Pressure and Constant Terminal Rate Cases for Infinite Reservoirs (Table I) in Van Everdingen and Hurst's ³³⁰ paper, for AQUCT(AQUTAB) equal to one. Previously, the internal table had a maximum dimensionless time (t_D) value of 100, which resulted in some models not matching the commercial simulator. The internal table has now been extended to a maximum dimensionless time value of 10,000, which should enable better consistency with the commercial simulator (#3099).
- 26) Improved the functionality of analytical aquifers by adding support for analytical aquifers to be used with OPM Flow's thermal modeling option. This includes adding support for AQUCT(TEMP) in the GRID section and AQUFETP(TEMP) in the SOLUTION section. Note that currently, one cannot use the restart facility when using the thermal model combined with analytical aquifers (#3109 and #4035).
- 27) Improved the BHP and IPR calculation so that the simulator obtains the highest valid production rate for a well (#3924). In addition, the current check for well operability using a well's IPR is different between standard and multi-segment wells. Now we check that all components have negative IPRs before making both well types inoperable. Secondly, fixed the hydrostatic correction for branched wells in the IPR calculation for multi-segment wells, as well as component and phase reference errors (#3926).

³³⁰ Van Everdingen, A. & Hurst, W., *The Application of the Laplace Transformation to Flow Problems in Reservoirs*. Petroleum Transactions, AIME (December, 1949).

- 28) The COMPDATA(DIRECT) parameter, that sets the direction of the connection, previously only supported uppercase values of X,Y and Z; this has now been improved by supporting both upper and lower case values ([#3171](#)). Fixes issue [#3164](#).
- 29) Previously, the *.DBG file contained hundreds of `computeBhpAtThpLimitProd()` messages per well, which made examining the output difficult, these messages have now been switched off, but are still available to developers via a compile switch ([#4097](#)).
- 30) Improved the error logging for the FAULTS keyword when FAULTS (FLTNAME) is greater than eight characters. Now the simulator issues a warning message and truncates FAULTS(FLTNAME) to eight characters ([#3065](#)) and [#3959](#)).

- 31) Improved the error handling associated with being unable to find a fault when using MULTFLT keyword, due to either the fault name not being defined in the FAULTS keyword, or the fault name being greater than eight characters:

```
An error occurred while creating the reservoir properties
Internal error: Could not set fault transmissibility multiplier 0 for fault FAULT01: Key FAULT01 not found.
```

```
FAULTS: invalid value 'FAULTLONG1' in record 1 for item 1
In file: MULTFLT-02.DATA, line 220
FAULTS(FLTNAME): Only names of faults up to 8 characters are supported. Will ignore excess characters.
See (#3062 and #3077).
```

- 32) Improved the error logging for MULTZ keyword, since this keyword is handled differently than the other MULT keywords in order to allow the PINCH keyword PINCH(PINCHMUL) option to be processed. Previously the error message was:

```
Error: An error occurred while creating the reservoir properties
Internal error: Region operations on 3D fields with global storage is not implemented
```

Now the simulator issues the following message:

```
Error: Unrecoverable errors while loading input: Problem with keyword MULTIREG
In MULTIREG-MULTZ.DATA line 224
region operation on 3D field MULTZ with global storage is not implemented
```

See [#3055](#) for further information.

- 33) Improved error logging for multi-column keywords, that is for SWOF etc., to more precisely inform the user the location of the error. Previously, if the number of columns was incorrect the simulator would issue the following message:

```
Error: An error occurred while creating the reservoir properties
Internal error: Number of columns in the data file is inconsistent with the ones specified
```

Now the simulator issues the following message:

```
Error: Problem with keyword SWOF
In MOD01-TEMP.DATA line 308.
Internal error: For table with ID 1: Number of input table elements (82) is not a multiple of table's specified
number of columns (4)
```

See [#3045](#) and [#3047](#) for further information.

- 34) Improved the handling of the ESMRY and ExtESmry files to add robustness to the concurrent usage of the files, so that one can safely load data from the files that are being created/updated by an active run ([#3028](#)).

- 35) Changed the terminal message for group switching control history. Previously, the full history was printed to the terminal, that is *RATE->FLD->RATE->FLD*. Now only the final control status is printed to the terminal and the previous format is now routed to the *DBG file (#4033).
- 36) Improved the convergence for problematic multi-segment wells by setting the default parameter for the command line parameter `regularization_factor_ms_wells_ = 1.0` (#3864).
- 37) Improved numerical performance by applying heuristic scaling of trueimpes weights for the cpr and cprw methods (#4194 and #4230).
- 38) Changed multi-segment well “Regularization Factor” from one to 100 to increase multi-segment wells capability to flow at lower rates and to fix a bug introduced with the recently added LET commit (#3906). See also #3859 for a discussion on the topic covered by this change.
- 39) Various Open Computing Language (“OpenCL”) improvements to the solver. See #3815, #3928, #3946, #3953 and #3973, which reverts #3953 due to compilation errors on certain C++ compilers.

OpenCL is a framework for writing programs that execute across various platforms consisting of central processing units (“CPUs”), graphics processing units (“GPUs”), digital signal processors (“DSPs”), field-programmable gate arrays (“FPGAs”) and other processors or hardware accelerators. OpenCL specifies programming languages (based on C99, C++14 and C++17) for programming these devices and application programming interfaces (APIs) to control the platform and execute programs on the compute devices. OpenCL provides a standard interface for parallel computing using task- and data-based parallelism. OpenCL is an open standard maintained by the *Khronos Group* a non-profit consortium.

- 40) Improved the handling of various PVT keywords, including: PVDO, PVDG, PVTO, PVTG, PVTW, DENSITY, and GRAVITY by incorporating the default behavior of using the previous table as the default for the next table, provided of cause the first table as been fully defined. For example, if there are two PVT regions, then one can default the second table by:

```
--
--      WATER PVT TABLE
--
PVTW
--      REF PRES  BW      CW      VISC      VISC
--      PSIA     RB/STB   1/PSIA  CPOISE    GRAD
--      -----  -----  -----  -----  -----
--      4840.0   1.019   2.7E-6  0.370    1*          / TABLE NO. 01
--                                     / TABLE NO. 02
```

This now works for all of the aforementioned keywords (#3058 and #3056).

- 41) Improved the *summary* utility, a standalone application that is used to list and extract data from SUMMARY files. The program will now list and query completion related summary vectors using keys of the form *Keyword:Wellname:CompletionNumber* e.g., *WOPRL:P1:3*. Previously, the keys were of the form *ComplKeyword:Wellname*, that is e.g., *WOPRL__3:P1*. See #3094.
- 42) In OPM Flow's Black-Oil Thermal model, temperature limits were applied during the Newton iterations that resulted in incorrect results. These have now been removed; thus, improving the overall results for these type of simulations (#712).
- 43) In OPM Flow's Black-Oil Thermal model energy calculations, the energy residual is now scaled so that it has the same relative order as the mass balance residuals. Previously, the simulator was using the same tolerances for the MB and CNV for energy and the various mass balance equations. This change makes the energy tolerance now more comparable with the ones for mass (#4037).
- 44) Improved the code base for identifying which wells are active and which wells are shut-in for both standard and multi-segment wells (#4101). See also #4102.
- 45) Previously when a well was changing control mode during a time step, the simulator printed each of control change. Now only the initial and final control modes are printed, and if the intial and final are

the same then no message is printed. For example:

```

BHP->THP->ORAT->THP is reduced to BHP->THP
and
BHP->THP->BHP will not be reported.
```

Note that the previous printing behavior is now routed to the *.DBG file (#4143).

- 46) Improved the convergence of newly opened wells (#4149). Secondly, only apply drift compensation when wells are active (#4102).
- 47) Improved well and group convergence by only accepting solutions for when the controls have not been violated (#4094). Also, improved model performance by avoiding oscillation between ORAT and LRAT, when they are essentially equal (#4134).
- 48) Wells under group control may violate their minimum THP due to the well's group imposing a lower rate, but are restricted from changing to rate control (see the WVFPEXP keyword in the SCHEDULE section). Under these circumstances, these wells would not be allocated gas lift gas, even though previously they were under gas lift. This has now been changed, so that wells will continue to receive gas lift gas as required (#4054).
- 49) Improved the standard well code by applying a "Regularization Factor" to avoid problematic wells prematurely shutting-in (#3957).
- 50) The simulator now allocates gas lift gas, or other artificial lift quantity, prior to attempting to solve the equations when the well is being tested if it can flow to surface (#4155).
- 51) Improved well tolerance criteria by relaxing the tolerance after six Newton iterations so that unsolvable wells remain open (#3859).

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

No.	Summary Keyword	Comment
1	BGPV, BOPV, BRPV and BWPV	Added block pore volume summary vectors BGPV, BOPV, BRPV and BWPV (#3016).
2	BOIP, BOIPG, BOIPL, BGIP, BGIPG, BGIPL, BVVIP, BRS, and BRV	Added SUMMARY vectors BOIP (block-level oil-in-place) and BGIPL (block-level gas-in-place in liquid phase), etc.. In addition, also add support for outputting the block-level dissolved gas-oil-ratio (BRS) and vaporized oil-gas-ratio (BRV) - see #3002 and #3886.
3	GEFF, WEFF, and WEFFG	Added support for the GEFF, WEFF, and WEFFG summary vectors that report the efficiency factors at the well (VEFAC) and group (GEFAC) levels. WEFFG additionally accounts for efficiency factors in a well's superior groups in the group tree (#3060).

Table B.2: New SUMMARY Keywords for the 2022-10 Release

Bug Fixes

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

- 1) Previously the simulator was unable to correctly process cells that were made inactive via the ACTNUM keyword, and then later in the deck re-activated using the EQUALS and ACTNUM keywords. This has now been rectified (#3049).

- 2) Fixed an issue with the aquifer models and the dune-alugrid module. The module provides an adaptive, load balancing, and unstructured implementation of the DUNE grid interface in two or three space dimensions supporting either simiex or cube elements (#4128).
- 3) There was an equilibration problem with cells having zero thickness, when the offending cells were used as numerical aquifer cells, this has now been corrected (#4127).
- 4) Corrected several issues with analytical aquifers and their connections. The simulator now issues a warning message if there are connections to undefined aquifers and for the case when there are aquifers with no connections. For the later scenario, the aquifer is disabled (#3102 and #4015).
- 5) When using the THERMAL option combined with BC keyword, the free boundary, that is the boundary conditions not stipulated by the BC keyword, would potentially have erroneous temperature data on the edge blocks. This has now been corrected in this release (#753 and #746).
- 6) Fixed a coding bug in the Cartesian mapping code (#4009).
- 7) The block-jacobi-ILU preconditioner did not work with cusparseSolver, due to zeros on the diagonal, the bug prevented the zeros being removed. The fix should improve performance for this solver (#3935).
- 8) Fixed a bug associated with copying tortuosity and diffusion coefficients if diffusion was not enabled, that is when the DIFFUSE keyword in the RUNSPEC section is not in the input deck. Previously, the implicit assignment operator was used causing the copying to occur unconditionally. This fix also improved run time performance for when diffusion is not enabled (#692).
- 9) Fixed two issues with the diffusion model. The first was related to conversion from molar to surface rates, the second was related to convergence and derivatives of the gradient. The changes solved issues with oscillations and low diffusion flux (#695).
- 10) Previously, for the DRSDT keyword (Solution Gas (Rs) Maximum Rate of Increase Parameters), was not written out to the RESTART file (#3977), and the actual units were missing from the output files, this has now been rectified (#3080).
- 11) Previously, the simulator would silently ignore any JFUNC keyword data in the GRID section, unless the end-point scaling option was activated through the ENDSCALE keyword in the RUNSPEC section, resulting in the run continuing without informing the user of the issue. Now the simulator issues an error message if the JFUNC keyword is present and the ENDSCALE keyword is absent, and will also now terminate the run (#3038).
- 12) Fixed a bug with the loading of vectors from the ESmry and EXTESmry files that resulted in the vectors being loaded twice (#3033 and #3059). In addition, fixed an issue with the start date format that should have seven items, with the last element representing milliseconds (#3154).
- 13) Fixed a bug with the writing of the ESmry summary files, caused by the commercial simulator and OPM Flow creating time vectors that are dummy data and not used. This caused an issue with the creating the ESmry file (#3100).
- 14) Fixed a bug with the incorrect calculation of the FOE (oil recovery factor based on STOIP) SUMMARY vector (#3048 and #3939).
- 15) Modified how gas lift assignment is performed. Now the maximum ALQ value is assigned to each gas lift producer at the start of the time step. This is done to allow the wells to attain a positive potential and thereby be considered as open. Then later in the time step, the full gas lift optimization procedure is used can adjust the ALQ to its "correct" value. Secondly, in some cases when gas lift is switched off by setting ALQ to zero, and later in the schedule is switched back on again, it might not be possible to determine BHP from THP and the iteration fails to converge due to small ALQ values. Now instead of aborting the gas lift optimization, we try increasing ALQ until we get convergence or until the maximum ALQ for the well is reached (#3868).
- 16) Fixed an issue with VFP calculations for two phase gas lift that did not work unless the rates are adapted to include a zero gas rate (#3876 and #3868).

- 17) There was an issue with the GASVISCT keyword in the PROPS section not being recognized by the simulator, which has now been rectified ([#3192](#) and [#3207](#)). However, there are still issues using this keyword, see Known Issues for details.
- 18) Fixed an issue associated with how the grid transmissibilities are calculated in parallel runs to ensure consistency in load balancing ([#3929](#) and [#3936](#)).
- 19) Fixed an error on how group constraints were applied. Now the simulator starts at FIELD level and moves downwards in the hierarchy checking the constraints. Thus, the simulator first checks if the group violates any constrains from above and then if it violates any individual constrains ([#4135](#)).
- 20) Refactored the code and fixed a bug associated with checking for violation of group constraints for multiple level of guide rates ([#4029](#)).
- 21) Fixed a bug introduced in [#3864](#), that caused the regularization term to be used in all subsequent linearizations until the next report step when the regularize variable is reset to false. With this change the regularization terms are only applied after the strict number of inner iterations are completed ([#3909](#)).
- 22) Fixed several bugs with the simulator not recognizing the supported KRNUM series of keyword and the DIFF keyword, as well as the unsupported HAXXXXXX, HMXXXXXX, and HMMULTXX series of keywords ([#3054](#)).
- 23) Using the KRNUM keyword resulted in a warning message stating incorrectly that the keyword was not supported, when in fact it is. This has now been corrected ([#4212](#) and [#4253](#)).
- 24) Previously when a keyword was missing a required terminating "/" the simulator would issue the following message:

```
Error: Unrecoverable errors were encountered while loading input
```

Which made finding the error challenging. Now the simulator will print the following message:

```
Error: Unrecoverable errors were encountered while loading input: Problem with keyword DATES  
In PROJ2_RESTART2.DATA line 408  
Keyword is not properly terminated
```

Thus enabling the user to identify and correct the error ([#3027](#) and [#3912](#)).

- 25) Previously, the simulator issued erroneous warning messages for the NNC keyword in GRID section when NNC(FACE1) and NNC(FACE2) were defaulted, this has now been corrected ([#3074](#)).
- 26) Fixed a bug with the equilibration of numerical aquifers when the numerical aquifer reference depth is significantly deeper than the OWC that caused the simulator to extrapolate the aquifer pressure to a NaN (Not a Number) - see [#3911](#).
- 27) Fix an issue associated with premature shutting of wells for when a well is controlled by a group that has zero rate. Due to numerical instability the well still gets an epsilon rate and skips the improved initialization used for wells with trivial rate. Adding an epsilon in the check is sufficient to keep the well open and ready for production when the group gets a non-trivial target ([#3887](#) and [#3888](#)).
- 28) Fixed an issue with the PVTG keyword if the Rv values all had the same value ([#3850](#), [#3881](#), and [#505](#)).
- 29) Previously, attempting to restart a run when the TSTEP and DATES keywords caused a non-monotonic schedule section, caused the simulator to abort - this has now been addressed. Secondly, if the SKIPREST keyword was missing from a restart run input deck, then the simulator would abort, again this has also been fixed ([#3035](#)).

- 30) The saturation pressures arrays, PBUB and PDEW, were previously written to the restart file using SI units instead of the pressure units for the model. This has now been fixed ([#4133](#)).
- 31) The command line parameter `enable-opm-rst-file=true`, allows for additional solution arrays to be written to the restart file, including the fluid viscosity arrays. However, WAT_VISC array data contained the gas viscosity data instead of the water viscosity data (issue [#4245](#)). This has now been corrected ([#4249](#) and [#4256](#)).

Thanks to Edmund Stephens for discovering the issue and providing an example model for analyzing the underlying issue.

- 32) If WELLDIMS(MXLIST) was set to zero in the RUNSPEC section, instead of one or I*, this resulted in the simulator throwing an exception when attempting to write out the restart file. This has now been rectified ([#3195](#)).
- 33) There was an error in the Salt Precipitation Model in how the solid salt calculation was used to reduce a cell's porosity. This has now been corrected by applying the calculation using the current porosity before being modified by the salt precipitation ([#716](#)).
- 34) Previously, the simulator would not run using the TEMP keyword in single phase water runs, this has now been fixed ([#3068](#)).
- 35) There was a bug associated with how the simulator calculated time on some operating systems, namely BSD, when the START date was 1 JAN 1900, or earlier. This has now be rectified ([#3101](#)).
- 36) There was a bug in the Two-Point Flux Approximation ("TPFA") version of local linearizer code that prevent it working for two-phase runs. This has now been corrected ([#713](#)).
- 37) Fixed a bug with the newly implemented TpfLinearizer for when the MULTFLT keyword is used in the SCHEDULE section ([#750](#), [#4232](#), [#4207](#) and [#748](#)).
- 38) A bug with the TpfLinearizer in parallel restarts caused the simulator to abort. This has now been fixed ([#4044](#)).
- 39) There was a bug associated with the `-use-gmres` command line option that requested that the Generalized Minimal Residual solver be used instead of the default Biconjugate Gradient Stabilized linear solver within the Newton iterations. The bug resulted in the command line option being ignored, this has now been fixed ([#4242](#) and [#4254](#)).
- 40) For models that only contain water, if the summary vector WBHP was requested, then the simulator would abort. This was because it was assumed that the oil phase was present when calculating WBP. This has now been fixed such that WBP is calculate based on the phases present (oil, gas and water). See [#3971](#) and issue [#3970](#) which is now closed.
- 41) For output of pore volume data, commit [6d3da3d](#) (PR [#3397](#)) introduced the notion of a "dynamic", pressure dependent pore volume and switched the PoreVolume aggregates to use reference conditions, for output to the PORV field in the *.PRT file. However, we failed to update all existing uses of the PoreVolume which introduced an inconsistency. In particular, for simulation models without hydrocarbons, for example in single-phase water runs, the numerator of the volume weighted average would include pressure effects through the rock compressibility, but the denominator would not. This has now been corrected and resolves issue [#3984](#).

Thanks to Edmund Stephens for discovering the issue and providing an example model for analyzing the underlying issue.

- 42) If the WELLDIMS(MXWSLIST) parameter was manually defaulted or set to zero, then the simulator would throw an exception when attempting to write to the restart file (see issue [#3194](#) for details). This has now been fixed ([#3210](#) and [#3195](#)).
- 43) In a gas-water system sometimes negative water saturations in the grid cells occurred, as per [OPM/opm-simulators#4002](#). This has now been corrected ([#707](#)).

- 44) Fixed a convergence issue in OPM Flow's Water Vaporization and Salt Precipitation models when water disappears in a cell due to water evaporation (#734).
- 45) When a well event occurs, for example opening or closing or changing control mode, we need to update the well state to match the new control type. In addition, we have to update the primary variables before attempting to solve for the wells. Previously, the primary well variables were not updated, this is now done correctly (#3907).
- 46) Fixed an issue with the way the code handled well connections (#3974).
- 47) There was a couple of issues with the well connections in parallel runs that have now been corrected, together with some refactoring of the code base (#3104).
- 48) Wells can either be STOPPED, allowing for potential cross-flow down-hole if requested by the WELSPECS(XFLOW) parameter, or SHUT for being isolated from the reservoir cells. However, STOPPED wells without cross-flow is inconsistent and results in numerical problems. Thus, when wells are declared as STOPPED without cross-flow, they are now treated as SHUT, the same as the commercial simulator (#3934).
- 49) When computing the sum of rates etc. over all well perforations, we need to cater for the case of distributed wells; that is wells present on more than one domain in a parallel run, i.e. we need to also sum up over all processes involved after performing the local sum. However, one of these global sums was missing in the function computeWellConnectionDensitiesPressures for producers when we computed the weights based on well transmissibilities. This has now been fixed (#3976). Note that distributed wells by default are not allowed, unless requested via setting the command line parameter *-allow-distributed-wells* equal to true.
- 50) In parallel runs, the number of local well perforations was not always correctly communicated between processes, especially if the distributed well had no perforations. This resulted in the simulator crashing. This has now been corrected (#3983).
- 51) Previously, the WECON keyword's economic limits were applied to both producers and injectors. This was incorrect, as the economic limits should only be applied to producers, this has now been rectified (#4151).
- 52) Fixed a bug in the multi-segment well model that resulted in non-finite values (#534).
- 53) For multi-segment wells using the WSEGVALV keyword to define a well segment to have a sub-critical valve ICD as part of a completion, if the value was shut then the rate and pressure drop for the value should be zero. However, this was not always the case. This has now been fixed by ensuring that rates and pressure drop for the valve are indeed zero for when the value is shut (#3964).
- 54) There was a potential sign error for the total flow rate for the top segment in multi-segment wells which has now been fixed (#4110).
- 55) Added the fluid flow velocity unit for multi-segment wells, required for exporting the data to the *.SUMMARY and *.RFT files (#3178).
- 56) Fixed a bug introduced with 06a8b0e in #3937 for standard wells that cause convergence issues on the GPU, for both cusparse and opencl implementations (#3958).
- 57) The error message for when VFPPROD tables had non-monotonic entries had the table number and the number of errors reversed. This output discrepancy has now been rectified (#3152). In addition, allowed the extrapolation of the tables to a greater range to improve the table lookup (#4098).
- 58) There was an issue with injection wells when the injection rate was set to zero for wells that were open to flow. This has now been fixed (#4116).
- 59) Fixed a bug with the WPIMULT keyword for not handling multiple WPIMULT keywords in the same time step correctly, as well as correctly defining the default values for the keyword as being any negative integer (#3067).
- 60) Fixed a regression bug with the WPIMULT keyword being used in an ACTIONX block (#3092).

- 61) Corrected an issue when using the WVFPEXP keyword in two-phase runs ([#4200](#) and [#4231](#)).

Known Issues

- 1) There is an issue with the GCONPROD keyword when GCONPROD(TARGET) is set to LIQ and both phases are not present in the input deck. This will cause the simulator to abort. The work around is to set GCONPROD(TARGET) equal to a phase that is present in the deck. See [#3970](#) for a discussion.
- 2) There is an error with the RSM header for summary vectors whose NUMS entry in the SMSPEC file is derived from more than a single number source (e.g., single region or segment ID). This applies to all block vectors (BGPV, BOPV, BWPV, etc.), connection level quantities (COPT, etc.), and inter-region flows such as ROFT etc. The work around is to plot the data in OPM ResInsight and right-click on the plot to view and copy the data. See issue [#3078](#).
- 3) OPM Flow does not support using LIQ as a well's preferred phase with the WELSPECS keyword, that is WELSPECS(TYPE) equals LIQ. This is a long-standing bug/omission in the simulator stemming from a somewhat naive internal notion of phases so we don't have an entry for a liquid phase, only for the distinct oil and water phases. For producing wells this mostly matters if you plot the WPI summary vector (productivity index for well's preferred phase). In the current treatment WPI will not have contributions from the water phase if the declared preferred phase is LIQ. For injecting wells WELSPECS's preferred phase doesn't really matter at all since the preferred phase is (typically) reset to the injected phase in WCONINJE/WCONINJH anyway. See issue [#3075](#).
- 4) If the simulator finds well connection being declared as connections via the COMPDATA keyword in the SCHEDULE section, then it writes out a warning message:

```
Warning: Problem with COMPDAT keyword
In SIM_PEE_Basic_Simulator.DATA line 535
The cell (0,6,4) in well INJ1 is not active and the connection will be ignored
Warning: Problem with COMPDAT keyword
In SIM_PEE_Basic_Simulator.DATA line 535
The cell (16,0,4) in well INJ2 is not active and the connection will be ignored
```

However, the reported cell references are offset by minus one, meaning the correct warning messages should be:

```
Warning: Problem with COMPDAT keyword
In SIM_PEE_Basic_Simulator.DATA line 535
The cell (1,7,5) in well INJ1 is not active and the connection will be ignored
Warning: Problem with COMPDAT keyword
In SIM_PEE_Basic_Simulator.DATA line 535
The cell (17,1,5) in well INJ2 is not active and the connection will be ignored
```

See issue [#3167](#) for details.

- 5) Pull request [#3192](#) fixed an incorrect JSON definition of the GASVISCT keyword in the PROPS section, that prevented a thermal model from running. However, thermal models containing the GASVISCT keyword will still not run, and instead will write out the following error message: Commenting out the keyword will enable the case to run. See issue [#3200](#) for details.

Error:

An error occurred while creating the reservoir properties
Internal error:Tried to get back() from empty DeckView

Error: Unrecoverable errors while loading input:Tried to get back() from empty DeckView

- 6) The tracer related output to summary file does currently not respect the command line variable - *enable-tracer-mode*, this means we may have the situation in which the input deck specifies tracer output, and the simulator is run without enabling the tracer model (*enable-tracer-mode=false*). In this scenario the trace SUMMARY vector output will consists of irrelevant tracer values.
- 7) The GDFILE keyword in the GRID section loads a grid file in various formats, with the FMTOPT parameter setting the format type of the file. If the variable FMTOPT is omitted then the default is for binary file input for the commercial simulator; whereas, OPM Flow derives FMTOPT from the file extension (*.EGRID or *.FEGRID), making FMTOPT superfluous. However, if the extension is lower case then OPM Flow may incorrectly determine the file type. The work around is change the extension to upper case.
- 8) As per previous releases of the radial model, the COORDSYS keyword item three must be set to COMP to complete the circle, this has not been implemented in this release. Also there appears to be a bug for full radial models when a well goes on BHP control that causes the well not to respect the BHP constraint, this eventually causes the well to die prematurely. See [#2640](#) for a discussion on the topic.
- 9) As in previous releases there are some issues with the OPERATE and OPERATER keywords associated with the input parsing; for various reasons a few of the fields require special case treatment in the grid processing, including (at least) MULTZ, PORV and ACTNUM, and for those keywords the OPERATE/OPERATER keyword doe not work. The work around is to use the MULTIPLY keyword instead.
- 10) For the UDQ ASSIGN operator after the terminating "/" normally any comments can be entered; however, if there is "/" within the comment field, as per:

```
ASSIGN FUNGLYLD 1.196 / Condensate Yield (63.5/56.7)/(1.0 - 0.065)
```

then the simulator will abort. The work around is to manually place the comment characters "--" after the ASSIGN terminating "/", like so:

```
ASSIGN FUNGLYLD 1.196 / -- Condensate Yield (63.5/56.7)/(1.0 - 0.06)
```

- 11) At the moment, one cannot initialize tracers using the EQUALS keyword. Instead use the array format, that is the keyword followed by the required number of values, or the TVDP keyword in the SOLUTION section to set the initial tracer concentrations as a function of depth.
- 12) Currently, gas tracers cannot be used if the dissolved gas phase, as per the DISGAS keyword in the RUNSPEC section, is active in the model.
- 13) There is a potential issue with left-handed grids that may cause the simulator to stop due to how the check for left-handed versus right-handed coordinate systems is performed in the corner-point processing code, which implicitly assumes that all pillars have well-defined, unique top-point coordinates. However, in some cases the pillar top points may be at the same coordinate location if there are no active cells along a particular pillar. Secondly, although OPM ResInsight may load the input grid, the display will be incorrect. Currently there is no work around for this except for re-generating the grid from the static model ([#3896](#)).
- 14) In some cases when the program stops the error message is written to the terminal but not to the *.PRT or *.DBG files. This is because the failing code is not aware of the C++ logging system. For example, this will occur if there is an error in parsing the grid data as the corner-point processing code is written in C and at the moment cannot call the C++ logging system. ([#3896](#)).
- 15) The summary vector RTIPTHEA, that defines the energy in-place between the initial and the current time for regions, is not supported unlike the FTIPTHEA and BTIPTHEA vectors. Secondly, the error message:

Warning: Problem with summary keyword RTIPTHEA
In RSM-THERMAL.data line 492
FIP region FIPHEA not defined in REGIONS section - RTIPTHEA ignored

is incorrect, as the message indicates that it is being treated like a named region, as per the FIP keyword, when it is actually a SUMMARY vector (#3870).

- 16) If there are cells that are very distorted, which can occur near fault planes, then the simulator may abort because it cannot calculate the pore volume of such cells. The work around is to re-generate the grid in the static model, taking care that the cells around the fault planes are more or less orthogonal (#2992 and #3770).
- 17) Currently the OPERATOR keyword in the EDIT section does not work with the DEPTH, TRANX, TRANY and TRANZ property arrays (#2994 and #748).
- 18) If a standard well is fully declared in an ACTIONX block which is then activated at a later date, and later the well is modified to be a multi-segment well using the WELSEGS and COMPSEGS keywords, then this will cause the simulator to abort with an assert failure. The solution to this issue is to not use this type of work flow in declaring wells (#2891 and #2895).
- 19) Although the ACTIONX EXIT command works as expected, it does not write out the requested RSM file at the end of the run. However, the other SUMMARY and RESTART files are written out (#2877).
- 20) Although the GCONSUMP keyword in the SCHEDULE section is fully implemented as documented, it is not possible to verify the output as the associated SUMMARY vectors are not written out, that is the SUMMARY sales gas vectors FGSR, FGST, GGSR and GGST, and fuel vectors FGCR, FGCT, GGCR, and GGCT have not been implemented (#2679).
- 21) There are small differences in the behavior of the NEXTSTEP keyword in the RUNSPEC section between OPM Flow and the commercial simulator that remain unresolved (#3745).

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