B.1 RELEASE 2024-04

The 2024-04 release consists of some new features and various improvements and bug fixes. The new features and improvements include the following highlights:

- Added support for the CO2SOL and H2SOL keywords for modeling CO_2 or H_2 injection in hydrocarbon reservoirs. These are similar to the existing CO2STORE and H2STORE keywords for modeling CO_2 or H_2 injection in saline aquifers.
- The option has been added to output the liquid phase H_2 mole fraction and vapor phase water mole fraction to the RESTART file when using the H2STORE option (RPTRST keyword mnemonics XMFH2 and YMFWAT).
- Added CO_2 mass in place summary vectors for the field and region level when using CO2STORE, including trapped masses based on the definition of immobile gas in the 11th SPE Comparative Solution Project.
- Added support for the SOURCE keyword for modeling a simple source term.
- Support has been added for WDFAC and WDFACCOR keywords in the SCHEDULE section. The option of setting connection specific D factors (Item 12 in COMPDAT) is now also supported.
- Added support for setting GCONPROD keyword item 7 (ACTION) equal to WELL. Added support for reason equals G (group) to the WTEST keyword item 3 (TEST).
- Added support for the DIFFAGAS and DIFFAWAT keywords to define respectively the gas phase and water phase diffusion coefficients based on a mass fraction formulation.
- Support has been added for the FBHPDEF keyword in the SCHEDULE section to define the default well BHP target for production wells and the default BHP constraint for injection wells.
- Support has been added for the SKIP, SKIP100, SKIP300 and ENDSKIP keywords.
- Support has been added for the NONNC keyword to deactivate non-neighbor connections.
- Added partial support for DATUMR and DATUMRX keywords in the SOLUTION section for use with block level summary keywords (BPP*).
- Limited support has been added for User Defined Tables (UDT).
- Added support for using region-level summary vectors in the defining expressions of field-level user defined quantities (UDQs).
- Support has been added for output of addition summary vectors, initialization arrays and restart arrays.
- A new brine-CO_2 mutual solubility model has been implemented from Spycher & Pruess, Transp. Porous Med., 2010. This model improves the accuracy of the solubility calculations in CO2STORE at temperatures above 100 degrees Celsius. In addition, a new keyword, ACTCO2S, has been added to choose between activity models.
- Added support for the PCFACT keyword in the PROPS sections to define the capillary pressure multiplication factor as a function of porosity change; used in conjunction with OPM Flow's Salt Precipitation model.
- Added support for the THCO2MIX keyword in the PROPS section to specify the thermal mixing models for salt in water, CO_2 dissolved in brine, and water vaporized in CO_2.
- Added support for using well lists (WLIST) in ACTIONX blocks with the following keywords: COMPDAT, COMPLUMP, WCONINJE, WCONPROD, WECON, WEFAC, WELOPEN, WELPI, WELSPECS, WELTARG, WGRUPCON, WPIMULT, WSEGVALV, WTEST and WTMULT.
- Added support for an expanded set of summary vectors to be used in defining expressions for UDQs and in the condition blocks of the ACTIONX keyword.

- Removed the need for a run-function in PYACTION blocks. EclipseState, Schedule, ReportStep and SummaryState are now available as attributes of the module opm_embedded. The code maintains backwards compatibility with the previous usage.
- Tooltips can now be enabled when writing code in a Python IDE by typing "import opm_embedded".
- An error will now be reported and the simulation stopped when the PYACTION keyword is used if flow was built without embedded Python.
- Repaired the PYACTION functions open_well(), shut_well() and stop_well(), which open/shut/stop a well at the specified report step, and added the option to use these functions at the current report step (if no report step is specified).
- Added PYACTION function insert_keyword() to insert a keyword at the specified later report step or at the current report step (if no report step is specified). This functionality is available for the keywords: FIELD, ENDBOX, GCONINJE, GCONPROD, METRIC, MULTX, MULTX-, MULTY, MULTY-, MULTZ, MULTZ-, NEXT, NEXTSTEP, WCONINJE, WCONPROD, WEFAC, WELOPEN and WELTARG.

B.1.1 NEW AND DEPRECATED COMMAND LINE OPTIONS

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

OPM Flow 2024-04 New And Deprecated Command Line Options

No.	Variable Name	Description	Default
1	--accelerator-mode	Added rocsparse option. A defined character string that selects the linear solver, usage: '--accelerator-mode=[none|cusparse|opencl|amgcl|rocalution|rocsparse]'.	"none"
2	--debug-emit-cell-partition	Added new command line option. A boolean value that determines whether (true) or not (false) to emit cell partitions as a debugging aid (#4938).	false
3	--explicit-rock-compaction	Added new command line option (#5089). A boolean value. Use pressure from end of the last time step when evaluating rock compaction (true) or not (false).	false
4	--external-partition	Added new experimental command line option (#4882). A quoted character string. Name of file from which to load an externally generated partitioning of the model's active cells for MPI distribution purposes. If empty, the built-in partitioning method will be employed.	""

OPM Flow 2024-04 New And Deprecated Command Line Options			
No.	**Variable Name**	**Description**	**Default**
5	--linear-solver	Added the dilu and cpr_trueimpesanalytic options (#5119, #5002, #4899). A defined character string that selects the configuration of solver. Valid options are: ilu0, dilu, cprw, cpr (an alias for cprw), cpr_quasiimpes, cpr_trueimpes, cpr_trueimpesanalytic, amg or hybrid (experimental). Alternatively, you can request a configuration to be read from a JSON file by giving the filename here, ending with '.json.'.	"ilu0"
6	--local-domains-ordering-measure	Replaced the "pressure" option with the "maxpressure" and "averagepressure" options. A defined character string that selects the subdomain ordering measure. Allowed values are 'maxpressure', 'averagepressure' and 'residual'.	"maxpressure"
7	--local-solve-approach	Changed the default value from "jacobi" to "gauss-seidel". A defined character string to choose the local solve approach. Valid choices are jacobi and gauss-seidel.	"gauss-seidel"
8	--local-tolerance-scaling-cnv	Changed the default value from 0.01 to 0.1. A positive real number. Set to a lower than 1.0 to use stricter convergence tolerance for local solves.	0.1
9	--min-strict-mb-iter	Added new command line option (#5173). An integer value defining the number of Newton iterations before relaxed tolerances can be used for the MB convergence criterion. Default -1 means that the relaxed tolerance is used when maximum number of Newton iterations are reached.	-1
10	--newton-max-error	Changed the default value from 1e+10 to 1e+100. A positive real value. The maximum error tolerated by the Newton method to which does not cause an abort.	1e+100
11	--newton-min-iterations	Changed the default value from 1 to 2. A positive integer value. The minimum number of Newton iterations per time step.	2
12	--pressure-max	Added new command line option. A positive real value. Maximum absolute pressure.	1e+99
13	--pressure-min	Added new command line option. A real value. Minimum absolute pressure.	-1e+99
14	--pressure-scale	Added new command line option. A positive real value. Scaling of pressure primary variable.	1

OPM Flow 2024-04 New And Deprecated Command Line Options			
No.	**Variable Name**	**Description**	**Default**
15	--tolerance-mb-relaxed	Added new command line option (#5173). A positive real value. Relaxed tolerated mass balance error that applies for iterations after the iterations with the strict tolerance.	1e-06
16	--use-implicit-ipr	Added new command line option. A boolean value. Compute implicit IPR for stability checks and stable solution search.	false
17	--ecl-enable-drift-compensation	Renamed to --enable-drift-compensation	true
18	--newton-target-iterations	Changed the default value from 6 to 10. A positive integer value. The 'optimum' number of Newton iterations per time step. This is an experimental option that is not used by the standard version of OPM Flow; the --time-step-control-target-newton-iterations option should be used instead.	10
19	--vtk-write-ecl-tracer-concentration	Renamed to --vtk-write-tracer-concentration	false
20	--ecl-enable-tuning	Deprecated (#5213)	
21	--ecl-newton-relaxed-tolerance	Deprecated	
22	--ecl-newton-relaxed-volume-fraction	Deprecated	
23	--ecl-newton-strict-iterations	Deprecated	
24	--ecl-newton-sum-tolerance	Deprecated	
25	--ecl-newton-sum-tolerance-exponent	Deprecated	

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

Table B.1: OPM Flow 2024-04 New and Deprecated Command Line Options

B.1.2 NEW FEATURES

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

1) The Forchheimer term has been added as an additional skin term that depends (explicitly) on the rate (#4832). Support has been added for WDFAC and WDFACCOR keywords in the SCHEDULE section. These keywords can be used to model a Forchheimer term in the well model either by specifying the D factor directly or by using the Dake model (#3661). The option of setting connection specific D factors (Item 12 in COMPDAT) is now also supported (#4971).

2) Support has been added for the FBHPDEF keyword in the SCHEDULE section to define the default well BHP target for production wells and the default BHP constraint for injection wells (*#4969*, *#3747*).

3) Added partial support for fluid in place region (FIP) output to the RPTSOL and RPTSCHED keywords (*#4982*, *#4978*, *#4980*, *#3756*). The simulator supports mnemonic FIP = 1 or 2, and partially supports FIP =3.

4) Added support for mechanical dispersion as a compile time option (*#4960*, *#3737*, *#847*). This adds support for the linear dispersion model described in the 11th SPE CSP benchmark *document* (Eq. 2.3).

5) Support has been added for specifying WCONPROD keyword item 12 (ALQ) with a user defined argument (UDA) (*#5033*).

6) Support has been added for specifying WSEGVALV keyword item 4 (AREAREST) with a user defined argument (UDA) (*#4873*).

7) Support has been added for the SKIP, SKIP100, SKIP300 and ENDSKIP keywords (*#5085*, *#3817*). Note that OPM Flow will skip data between the SKIP300 and ENDSKIP keywords whereas the commercial black-oil simulator will ignore the SKIP300 keyword.

8) Added support for defining a fluid mass (and enthalpy) source term within a grid cell using the new OPM Flow specific SOURCE keyword in the SCHEDULE section (*#5050*, *#3835*, *#1106*, *#5107*, *#3864*).

9) Support has been added for the NONNC keyword in the RUNSPEC section to deactivate non-neighbor connections (*#5134*).

10) Added support for the DIFFAGAS and DIFFAWAT keywords in the PROPS section to define respectively the gas phase and water phase diffusion coefficients for each pseudo component and for each PVT region. The DIFFAGAS and DIFFAWAT keywords are equivalent to DIFFCGAS and DIFFCWAT keywords, but assume a mass fraction formulation of diffusion rather than the default mole fraction formulation (*#5143*, *#3878*).

11) Added partial support for DATUMR and DATUMRX keywords in the SOLUTION section for use with block level summary keywords (BPP*) (*#5241*, *#5240*, *#3958*).

12) Added support for using region-level summary vectors in the defining expressions of field-level UDQs (*#5250*, *#5247*, *#3977*, *#3980*). For example:

```
UDQ
  DEFINE FURE2 (ROIP_RE2 2)+(ROIP_RE2 4)+(ROIP_RE2 5) /
/
```

13) Added support for GCONPROD item 7 (ACTION) equal to WELL. Added support for reason WTEST item 3 (TEST) equals G (group) (*#5172*, *#3894*).

14) Limited support has been added for User Defined Tables (see the UDTDIMS keyword in the RUNSPEC section and UDT keyword in the SCHEDULE section), one-dimensional tables are now supported (*#4940*, *#3728*). The maximum number of dimensions in any given User Defined Table is specified by item 4 (MXDIMS) of the UDTDIMS keyword.

15) Added support for setting a no flow and constant temperature boundary condition for the 11th SPE CSP benchmark cases B/C (*#865*).

16) Added support for updating individual well properties for one or more wells (based on a well name, well name pattern or well list) using the WELSPECS keyword in the SCHEDULE section. In particular, this revised logic enables the controlling group to be changed without affecting any other well properties such as the location of the well head or the well reference depth (*#3703*). As an example, this new WELSPECS behavior enables the following usage:

```
ACTIONX
  A  1 /
  WOPR 'P*' < 123.4 /
  /
  WELSPECS
    '?' 'LOWPRESS' /
  /
ENDACTIO
```

to move all wells matching the pattern 'P*', and with a low oil production rate, to the group 'LOWPRESS'. This could, in turn, apply a different set of group-level production controls to those wells.

17) A new brine-CO_2 mutual solubility model has been implemented from Spycher & Pruess[356]. This model improves the accuracy of the solubility calculations in CO2STORE at temperatures above 100 degrees Celsius. In addition, a new keyword, ACTCO2S, has been added to choose between activity models. The original CO2STORE solubility and salt activity models are currently the default behavior (i.e., ACTCO2S keyword model number 3) (*#3694*).

18) Added the CO2SOL and H2SOL keywords in the RUNSPEC section which activate either dissolved carbon dioxide (CO_2) or hydrogen (H_2) in the water phase, where CO_2 or H_2 is represented by the SOLVENT pseudo component, using the simulator's CO_2-Brine or H_2-Brine PVT model. The CO2SOL and H2SOL keywords can be used when modeling CO_2 or H_2 injection in depleted hydrocarbon reservoirs (*#3764*, *#851*, *#4991*).

19) Added support for the PCFACT keyword in the PROPS sections to define the capillary pressure multiplication factor as a function of porosity change (*#3857*). Currently the keyword is used in conjunction with OPM Flow's Salt Precipitation model.

20) Added methods to the Python module opm.simulators.BlackOilSimulator to access primary variables and fluid state variables (*#4950*).

21) Added docstrings for the Python bindings. Currently, the docstrings can be used to get context help in editors or in IPython. However, the plan is to also use these docstrings to generate sphinx documentation for the Python bindings (*#5242*).

22) Added PYACTION functions insert_keyword(const std::string& deck_string) and insert_keyword(const std::string& deck_string, std::size_t report_step) to insert a keyword. A keyword can be inserted at a later report step or at the current report step; inserting a keyword at a past report step or at a report step exceeding the total number of report steps throws an error (*#3994*).

23) Added support for the THCO2MIX keyword in the PROPS section to specify the thermal mixing models for salt in water, CO_2 dissolved in brine, and water vaporized in CO_2 (*#4012*).

B.1.3 IMPROVEMENTS

Improvements include:

1) Previously, the simulator would perform unnecessary network iterations if all wells belonging to the network were in history mode. The simulator has been updated to avoid this and only compute the network pressures for reporting purposes (*#4881*).

2) Previously, if no well THP constraint had been specified then the THP would be set to zero. The simulator has been updated so that the THP would only be set to zero if no valid VFP table has been provided. If a VFP table has been provided but no THP constraint has been specified then the THP value is calculated for reporting purposes. In addition, if the well is part of a network then the THP value is required for a constraint check (*#4930*).

[356] *Spycher, N., Pruess, K. A Phase-Partitioning Model for CO2–Brine Mixtures at Elevated Temperatures and Pressures: Application to CO2-Enhanced Geothermal Systems. Transp Porous Med 82, 173–196 (2010).*

3) Updated code to output more information and avoid harsh termination due to assert in StandardWellPrimaryVariables (#4946).

4) The simulator has been updated to reduce well connection transmissibility factor due to salt precipitation (#4919).

5) The simulator has been updated to compute the reservoir volume rates based on the average pressure and temperature in the well for injectors in THERMAL cases (#4826).

6) The code has been updated to ensure there is a non-zero initial guess for well rates, and that non-zero water/gas fractions are available from the previous time step for the (explicit) VFP table interpolation. Previously, if this was not the case then the well was likely to converge to the zero rate and/or zero fractions case and would be deemed to be inoperable (#4952).

7) The simulator has been updated to allow the creating or opening of a well as a result of an ACTIONX keyword block in the middle rather than at the end of a report step (#4749).

8) Previously, numerical problems were reported as errors in the print file (*.PRT), before continuing the simulation. This resulted in successful runs being incorrectly reported as having errors. The code has been updated to report them as problems rather than errors (#4977, #4957).

9) Rerouting is now allowed in the standard and extended network models (#3695, #4945).

10) Added support for networks with multiple fixed-pressure nodes (#3702, #4915).

11) Added extra information about well convergence failures to the INFOITER file (if this file has been requested, the default is for this file not to be output) (#4975).

12) The simulator will now log a problem if asked to continue with the run after a convergence failure of the non-linear solver has occurred, by specifying the command line option *--solver-continue-on-convergence-failure=true* (#4979).

13) If parsing strictness is set to low with the command line option *--parsing-strictness=low* and no matching wells are found by various keywords in the SCHEDULE section then a warning will be issued and the run will continue (#4905, #3698).

14) Previously, numerical problems during well testing would be caught at a higher level, causing time step chops in serial mode and possibly MPI communication errors in parallel. With this change wells that experience such problems during testing will simply not open, and the MPI errors are no longer present (#5032).

15) A guard has been added against not a number (NaN) from certain expressions (e.g. evaluating a power of a negative number) in the valve models (#5041).

16) If Hierarchical Data Format (HDF5) input/output is requested but no support is available then an exception is thrown early instead of logging later an error when save/load is to be performed (#5042).

17) Functionality has been added for computing an implicit Inflow Performance Relationship (IPR). Moreover several functions are now utilizing this for stability checking, estimating the operability of stopped/unconverged wells and searching for solutions (VFP/IPR intersections) in problematic cases. In addition, direct computation of potentials is included. For the new code to take effect, currently simulations must be run with both options *--local-well-solve-control-switching=true* and *--use-implicit-ipr=true* (#4986).

18) The code has been updated to apply MULTX, MULTY and MULTZ transmissibility multipliers to boundary transmissibilities (#5047).

19) The name of the destination file is now included in warning messages about unhandled report keywords (#5048).

20) Reformatted production and injection reports in the Print file (*.PRT) by removing dashed lines between records (#5049).

21) Previously information about parallel runs was only output to the standard out. To help with debugging and replicating cases (e.g. in case of crashes) without saved standard output, the information about MPI processes and OMP threads is now also sent to the PRT file (#5031).

22) The test of whether the gas phase at the well connection is saturated or not has been made more robust by simply comparing the oil-gas ratio with saturated oil-gas ratio at the connection pressure (#5075).

23) Output of reservoir volumes to the Print file (*.PRT) has been added for custom fluid in place (FIP) regions. In addition, the compatibility of the output with the commercial simulator has been improved (#5068).

24) Previously the flow reports in the PRT file were restricted to wells active on the current MPI rank. The simulator now outputs the flow reports for all wells active at the current report step (#5090).

25) The output of Newton progress has been improved for the NLDD option (#5104).

26) Added parallel well domain and error logging for NLDD (#5116).

27) Currently the NLDD option requires the command line option *--matrix-add-well-contributions=true*. An error message will be now be generated if NLDD is used without this option set (#5120).

28) Improved handling of wells with zero rate where cross-flow is turned on and off (#5139, #3880).

29) The simulator has been updated to ignore the COORDSYS keyword in the GRID section (#5161). Note that the simulator will stop if the number of reservoir grids to process, set using the NUMRES keyword in the GRID section, is greater than one.

30) Improved error message to be more informative when an exception occurs in computeWellPotentials() (#5170).

31) The simulator now removes possible old simulation output files from the specified output directory before logging starts (#5168).

32) A number of minor improvements have been made to the time reporting output including the addition of setup time (#5174).

```
================    End of simulation     ===============

Number of MPI processes:         1
Threads per MPI process:         2
Setup time:                      0.29 s
  Deck input:                    0.21 s
Number of timesteps:           123
Simulation time:                 0.98 s
  Assembly time:                 0.31 s (Wasted: 0.0 s; 0.0%)
    Well assembly:               0.04 s (Wasted: 0.0 s; 0.0%)
  Linear solve time:             0.23 s (Wasted: 0.0 s; 0.0%)
    Linear setup:                0.06 s (Wasted: 0.0 s; 0.0%)
  Props/update time:             0.19 s (Wasted: 0.0 s; 0.0%)
  Pre/post step:                 0.14 s (Wasted: 0.0 s; 0.0%)
  Output write time:             0.07 s
Overall Linearizations:        483      (Wasted:     0; 0.0%)
Overall Newton Iterations:     360      (Wasted:     0; 0.0%)
Overall Linear Iterations:    1311      (Wasted:     0; 0.0%)
```

33) The code now avoids unnecessarily looking up the artificial lift quantity (ALQ) for injection wells (#5221).

34) Improved formatting of small numbers in adaptive time stepping output (#5237).

35) With multi-segment wells, the segment pressure can be lower than the BHP, so it is not desirable to use the BHP lower limit to limit the segment pressures. The simulator has been updated so that the

BHP lower limit is only used to limit the BHP; a lower limit of zero is imposed on the segment pressure (#5234).

36) The simulator has been updated to allow for the possibility that not all well connections are in active cells for the purpose of calculating the WBPn summary vectors. This situation might arise for example when "re-parsing" portions of the SCHEDULE section following the successful triggering of an ACTIONX block (#5258, #3988).

37) Avoid repeatedly getting a parameter value in a performance-critical section of the code, which was causing a significant performance loss for the Norne model, by getting the parameter once in the constructor instead (#5318).

38) Avoid expensive call to FaceDir::FromIntersectionIndex() in a performance-critical section of the code, this fixes a significant performance regression on the order of 5% or more in the flux calculations that was introduced earlier (#898).

39) Added support for using well lists (WLIST) in ACTIONX blocks with the following keywords: COMPDAT, COMPLUMP, WCONINJE, WCONPROD, WECON, WEFAC, WELOPEN, WELPI, WELSPECS, WELTARG, WGRUPCON, WPIMULT, WSEGVALV, WTEST and WTMULT (#3741).

40) Output computed surface densities for CO_2 and Brine to the PRT file if the CO2STORE option is enabled (#3730).

41) The simulator will now output the time step in units of hours when using laboratory (LAB) units. Previously units of days would have been used for all unit systems (#3829).

42) Improved the handling of errors related to the grid keywords. Missing or ambiguous keywords are detected and the error messages list the valid options (#3849, #3551).

43) Added support for pattern matching in the MULTFLT keyword (#3851).

44) Improved the error reporting for SALTSOL tables when a column is missing (#3850).

45) Added support for setting the same region for the source and target in the MULTREGT keyword. In this case the multipliers will be applied to all connections within the specified region as well as to connections between the specified region and all other regions (#3845).

46) The code has been updated so that for mixed wettability systems it no longer scales the negative part of the oil-water capillary pressure curve when using the SWATINIT keyword (#3720). This behavior is controlled by an option in the commercial simulator.

47) The CO2STORE option could lead to slow runs if a lot of extrapolation was done resulting in numerous warning messages. These messages have been turned off unless the debug option has been set. Note that extrapolation of tables can be avoided by limiting the temperatures and pressures using the *--temperature-min*, *--temperature-max*, *--pressure-min* and *--pressure-max* command line options (#3858).

48) The simulator now outputs a meaningful error message in the case where it fails to open a potentially corrupt file (#3870).

49) Improved parsing of sections in the input deck and support for optional sections EDIT, REGIONS and SUMMARY (#3863).

50) Enforce consistency checks on keywords specifying the standard and extended network models respectively (#3885).

51) The simulator has been updated to check whether the standard network model is active when initializing a network balancing operation. Previously, the simulator would only check for the extended network model. This was an issue because the pressure convergence tolerance is set to zero unless a network model is active (#3874).

52) Add support for operations (e.g. EQUALS) on the MINPVV array (#3897).

53) Added support for numbers in user defined region set names, for example FIPAB1 and FIPAB2 (#3979).

54) Allow the use of the FIELD group for selected group level keywords when handling UDQs and especially ACTIONX condition blocks, for example GGOR 'FIELD' > 123.4 (#3993).

55) Allow an expanded set of summary vectors to be used in defining expressions for UDQs and in the condition blocks of the ACTIONX keyword. In principle, this change enables using all known summary vector categories as part of the defining expressions in a UDQ, but additional testing is needed before claiming to fully support such usage (#3968).

56) The simulator will now report an error if the PYACTION keyword is used when flow has been built without embedded Python (#3998). Previously, only a warning message would have been reported.

57) Removed the need for a run-function in the Python code in PYACTION. The EclipseState, Schedule, ReportStep and SummaryState have been made available as attributes of the module opm_embedded instead. This enables tooltips for writing code in a Python IDE, after importing the library as "import opm_embedded", typing "opm_embedded." will show the tooltips. The code will still be backwards compatible (#3986).

58) Added check that when a non-default THP constraint has been specified for a well that a valid VFP table has been defined (#4005).

59) Previously, when temperature results were not available 0 K would be converted to the units system specified in the deck and output to the SUMMARY file (for example -273.15 or -459.67 depending on the unit system). The simulator will now output a zero temperature in the specified units system when temperature results are not available (#4013).

60) Added PYACTION functions to open, close or shut a well without specifying the report step (#4019).

61) Added an error message if an attempt is made to use the COMPSEGS keyword to define the well segment connections before the structure of the multi-segment well has been defined using the WELSEGS keyword (#4031).

62) The code now determines if a history matching producer with a reservoir volume rate (RESV) target is subject to a zero rate constraint by checking if the specified historic rates for oil, gas and water are all zero (#4039).

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

No.	Summary Keyword	Comment
1	NPR, GNETPR	Added support for output of network pressures based on rates at end of the time step (#3701, #4914). Note that GNETPR is an alias for NPR included since NPR can cause problems for certain post-processors.
2	CGFRF, CGFRS, COFRF and COFRS	Added support for output of well connection free gas, solution gas, liquid oil and vaporized oil flow rate vectors (#5010, #3782).
3	CDFAC	Added support for output of well connection D factor (#4832).
4	FGMIP, FGMGP, FGMDS, FGMTR and FGMMO	Added CO_2 mass in place summary vectors for the field when using the CO2STORE option: total mass in place, mass in gas phase, mass dissolved in water phase, mass in trapped gas phase and mass in mobile gas phase (#5114, #3868).
5	RGMIP, RGMGP,	Added CO_2 mass in place summary vectors for FIP regions when using the

	RGMDS, RGMTR and RGMMO	CO2STORE option: total mass in place, mass in gas phase, mass dissolved in water phase, mass in trapped gas phase and mass in mobile gas phase (*#5114*, *#3868*).
6	BGIP, BGIPL	Added support for block total gas in place (BGIP) and block gas in place in the water phase (BGIPL) for gas-water systems (*#5188*).
7	BPPO, BPPG and BPPW	Added support for output of block level datum depth corrected phase pressures (*#5240*, *#3959*, *#3958*).
8	FGKDI, FGKDM, FGKTR and FGKMO RGKDI, RGKDM, RGKTR and RGKMO	The 11th Society of Petroleum Engineers Comparative Solution Project (http://spe.org/csp) defines the "immobile free-phase CO_2" as "CO_2 at saturations for which the non-wetting phase relative permeability equals zero". Field and Region level summary vectors have been added when using the CO2STORE option based on this definition as follows (*#5281*, *#4010*): Gas Moles in the Immobile Gas Phase (Non-wetting relative permeability equals zero), Gas Moles in the Mobile Gas Phase (Non-wetting relative permeability greater than zero), Gas Mass in the Immobile Gas Phase, and Gas Mass in the Mobile Gas Phase.

Table B.2: New SUMMARY Keywords for the 2024-04 Release

Support has been added for the following initialization output as described by the comments in Table B.3.

No.	Mnemonic	Comment
1	MULTX, MULTY and MULTZ MULTX-, MULTY- and MULTZ-	Added support for outputting transmissibility multiplier arrays to the INIT file. The MULTX, MULTY and MULTZ arrays are always written. If the first item of the GRIDOPTS keyword is NO then only the MULTX-, MULTY- and MULTZ- arrays that have be specified in the deck will be written. If the first item of the GRIDOPTS keyword is YES then all transmissibility multiplier arrays are written (*#3997*).
2	SWATINIT	The simulator will now output the SWATINIT array to INIT file if it exists in the input deck (*#3832*).

Table B.3: New Initialization Output for the 2024-04 Release

Supported has been added for the following restart output as described by the comments in Table B.4.

No.	Mnemonic	Comment
1	RESIDUAL	Added option to output the residuals at the end of the time step. To activate this output the command line option *–enable-opm-rst-file=true* should be specified and the mnemonic RESIDUAL should be added to the RPTRST keyword (*#4937*).
2	XMFH2, YMFWAT	The option has been added to output the liquid phase H_2 mole fraction and vapor phase water mole fraction (XMFH2 and YMFWAT) when using H2STORE. To activate this output the command line option *–enable-opm-rst-file=true* should be specified (*#4964*). Previously the mnemonics XMFCO2 and YMFWAT were only available for CO2STORE.
3	RSWSOL	Support has been added for output of dissolved solvent to water ratio RSWSOL (*#4991, #3764*, *#851*).
4	FLOWS-, FLORES-	Support has been added for output of negative direction inter-block flows at surface conditions (FLOWS-) and at reservoir conditions (FLORES-) (*#5038*, *#3823*, *#854*).
5	RPORV	Support has been added for output of pore volumes at reservoir conditions

		using the RPORV mnemonic of the RPTRST keyword (#5092).
6	CONV	Added partial support for output of cells causing convergence problems for the residuals of the oil, water, gas, polymer, brine and solvent equations to the restart file using the CONV mnemonic of the RPTRST keyword (#5054, #5112).
7	PCGW	Added support for outputting gas-water capillary pressure (Pcgw) to the restart file using the PCGW mnemonic of the RPTRST keyword (#5126).
8	FIPOIL, FIPWAT, FIPGAS, RFIPOIL, RFIPWAT, RFIPGAS	Added support for output of fluid in place arrays for oil, gas and water to the RESTART file. The SFIPOIL, SFIPWAT and SFIPGAS are the surface conditions volumes for oil, water and gas respectively (these are aliases for FIPOIL, FIPWAT and FIPGAS). The RFIPOIL, RFIPWAT and RFIPGAS are the reservoir conditions volumes for oil, water and gas respectively (#5224, #3952).

Table B.4: New Restart Output for the 2024-04 Release

B.1.4 BUG FIXES

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

1) The simulator has been updated to use the applyRestartSwatInit() member function instead of directly mutating a data member of the EpsInfo structure. This way we defer the PCOW re-scaling for SWATINIT to a context with a more complete view of the changes needed to convey the information to all components involved. With this change the simulator is mostly able to reproduce the base run in a restart run from the end of the historic period for a real field case that has strong SWATINIT scaling of the oil-water capillary pressure function (#4944, #3731).

2) The code was updated to include a new event to address an issue with a reported case where WELOPEN failed to open a well previously shut due to an economic limit (#4924, #3707).

3) The logger is now initialized before parsing (#5007). Previously, uninitialized values would have been used when the parser logged some errors.

4) Fixed an issue where BCPROP would be ignored if it was not set in the first time step. This update makes it possible to set BCPROP later in the schedule (#4912, #833).

5) Previously, a well with shut-in instruction "shut" that changes to non-operable during an iteration will give the message well xxx gets SHUT during iteration, but no further actions are triggered. This is due to the flag changed_to_stopped_this_step_ not being set. The simulator has been updated so that a non-operable well will give the message well xxx gets STOPPED during iteration (irrespective of it's shut-in instructions), and at the end of the time-step get closed according to it's shut/stop instruction (with accompanied message) (#5014, #4902).

6) Fixed an issue where there was an inconsistency between well BHP and perforation pressures, and between well rate and perforation rate (#5015).

7) Fixed a bug in the Gauss-Seidel NLDD approach that would actually do a Jacobi initialization for the very first iteration of a local domain solve. We add the maxpressure option for Gauss-Seidel NLDD domain ordering, and make it the new default ordering, and make Gauss-Seidel the default approach. Finally, we make the default number of domains equal to one domain per 1000 cells, instead of just a single domain, and tweak the default convergence tolerance scaling for local solves. These changes are intended to lower the bar to testing the *–nonlinear-solver=nldd* option. You still need to use *–matrix-add-well-contributions=true* to run with NLDD, otherwise the defaults should be sufficient for reasonable behavior (#5021).

8) Previously, combining *–load-step* with different *–output-dir* triggered a warning. The code has been updated to not issue a warning since these options can safely be used together (#5024).

9) Previously, when singular matrices occurred when solving multi-segment wells an exception would be thrown only on one process resulting in MPI errors about truncated messages. The code has now

been updated so that all MPI processes will throw, terminate the non-linear solver and cut the time step to continue the simulation (#5025, #5036).

10) Fixed the sign of the production rate for group pressure maintenance (#5026).

11) Get a complete list of fluid in place (FIP) regions from FieldPropsManager rather than from SummaryConfig, which only holds regions with summary keywords (#5034, #3813).

12) Previously an exception thrown by WetGasPVT::saturationPressure due to failure to converge within 20 iterations was only seen on one MPI rank and the others continued. The code now communicates the problem and throws on all MPI processes. This results in the time step being cut as a result and simulation continuing (#5046).

13) Ensure the input temperature is used in the density calculations in the initialization (#5058).

14) Avoid modifying outputDir, leave empty if defaulted (#5073).

15) The code has been updated to only output FLOWS and FLORES for interior cells. This fixes an issue with parallel output of FLOWS and FLORES (#5043).

16) The setting of solvent values has been made conditional on the SOLVENT being active (#5086).

17) Previously when assembling the acceleration pressure drop terms for multi-segment wells certain derivatives for reverse flow were skipped. The code has been rewritten to fix this issue and improves convergence in some cases (#5040).

18) Code has been updated to use the gas pressure rather than the oil pressure in gas-water simulations when modifying rock properties due to compaction (#5081).

19) The code has been updated to honor the default minimum number of Newtons iterations. Previously the simulator would perform a minimum of two Newton iterations even though the default was one (#5094). Note that also the default has been changed from one to two.

20) The code has been updated to use the arithmetic average of compaction transmissibility multipliers rather than the upstream value (#5088, #858).

21) A fix has been provided for a crash when cleaning up the Damaris mesh offset variable due to the shared memory buffer size being off by one (#5109).

22) The simulator now supports at least NTFIP (REGDIMS keyword item 1) distinct regions for inter-region flow to avoid a possible segmentation failure (#5117).

23) A couple of changes have been made to fix network convergence issues. The lower bound on the network pressure update has been removed as this could lead to convergence issues. In addition, the convergence tolerance has been tightened by a factor of 10 for wells that are controlled under a dynamic THP-limit since the default (standard) well tolerance was not sufficiently strict to get network convergence in some cases (#5128).

24) Previously the solvent production rate was not included in the total gas production rate when applying the gas production rate limit (GRAT) in the well control keyword WCONPROD. The gas production rate limit is now applied to the total gas production rate including both the gas and solvent pseudo components (#5140).

25) A bug revealed by (#5124) in the local well control switching option where previously stopped wells would re-open during the local solve has been fixed (#5129).

26) Previously, NEXTSTEP was ignored if the user did not run OPM Flow explicitly setting the command line parameter *–enable-tuning=true*. Now NEXTSTEP will be applied regardless of which parameter value was set (#5215).

27) The handling of the NEXTSTEP keyword in an ACTIONX block has now been fixed (#5222).

28) The code has been updated to ensure that the simulator does not advance beyond the current report step and that the next time step is not too small if the NEXTSTEP keyword is used in an ACTIONX block (#5259).

29) Fixed an issue where previously the low parsing strictness command line option was not being respected when reprocessing the schedule section after the application of an action (#5220).

30) Fixed a crash in the Python module due to duplicate symbols that depended on the order of the object libraries in the linker command during the build (#5235).

31) Added missing convergence metrics to the domain convergence report. Previously, for NLDD local solves the metrics were always zero and non-converged local solves were accepted (#5249).

32) The code has been updated to call loadRestartData on all processes even if there are no local wells since group data is still required (#5252).

33) Corrected formatting of debug message in MultisegmentWellSegments.cpp to avoid throwing exception in libfmt (#5261).

34) Fixed a potential out-of-bounds reference that could occur if there are no wells (#5264).

35) Fixed a segmentation fault due to taking a reference to a temporary variable in the WBP calculation service (#5267).

36) Fixed a bug introduced when the ROCm dependency on OpenCL was removed (#4883), which disabled the option to run the rocSPARSE and cuSPARSE backends with the optimized version of the block Jacobi incomplete lower-upper (ILU) preconditioner (#5255).

37) Fixed dangling references in Logger for test_LogOutputHelper that can result in a segmentation fault that has been seen on the ppc64el architecture (#5263).

38) The code now makes sure that the fast AMG preconditioner is reconstructed when performing an update (#5284).

39) Fixed an issue where the send and receive buffers were the same which caused an MPICH error on MPICH based Red Hat Enterprise Linux 7/8 builds (#5297).

40) Fixed a bug which caused an error whenever item 4 (PINCHCAL) of the PINCH keyword was set to ALL. The case where one of the pinched out cells has zero z-direction permeability (or z-direction transmissibility multiplier) is now supported. However, the ALL option is still not fully supported (#707, #701).

41) Fixed an integer overflow in the initial processing of grids with more than 134 million cells that would cause a segmentation fault (#710).

42) The simulator now correctly allows for solvent flux when the dissolved gas in water option has been activated by the DISGASW keyword in the RUNSPEC section (#866).

43) The 'meaning' variables are now initialized to avoid potential out-of-bounds dereferences (#880).

44) Fixed a bug where setting the saturation table number (SATNUM) in the COMPDAT keyword (item 7) to a value other than the cell SATNUM resulted in a segmentation fault in two-phase cases. The simulator now checks which two-phase approach is active and sets the correct relative permeability parameters accordingly (#3739).

45) Fixed an issue where the simulator interpreted the month 'FEB' in an ACTIONX condition as a field-level summary vector and wrote a value of zero rather two (for February) to the restart file. This resulted in an unhelpful error message when later trying to perform a restart (#3826).

46) The simulator now assumes that the reservoir density and internal energy of CO_2 and H_2 are not affected by their water content (#3806). This avoids the use of calculations based on the ideal gas assumptions implemented in simpleHuDuanH20.hpp. The formulation is now as in the 11th SPE CSP.

47) The simulator previously assumed that all UDQs loaded from the restart file had an UPDATE status of ON (#3808). The simulator now inspects the actual update status and uses that to configure the UDQ when restarting the simulation (#3833).

48) Previously the simulator conflated history control with the WHISTCTL keyword setting, thus failing to respect any control mode setting in the WCONHIST keyword in the case of a simulation restart in the historic period. The WHISTCTL keyword setting has been decoupled from that of the control mode setting specified in the WCONHIST keyword thereby supporting both modes when a simulation is restarted in the historic period. This, in turn, fixes a simulation restart on a real field (#3854).

49) Fixed output of the group hierarchy chart to the PRT and DBG files as requested by the WELSPECS mnemonic of the RPTSCHED keyword (#3856).

50) Corrected the units for region level CO_2 summary vectors RGCDI, RGCDM and RWCD to be moles instead of surface volumes (#3866).

51) Fixed support for the not equals operators '.ne.' and '!=' in ACTIONX keywords (#3893).

52) Account for well and/or group efficiency factors when evaluating rates for non-default region sets, for example ROPR_ABC and ROPT_ABC (#3955).

53) The code has been updated so that TSINIT (item 1) of the TUNING keyword only applies to the next time step (#3953).

54) Fixed the handling of the MULTX, MULTX-, MULTY, MULTY-, MULTZ, MULTZ- keywords and EQUALS MULT* keywords in the EDIT section. Previously multiple occurrences of these keywords in the EDIT section would have been applied cumulatively. Now the EDIT section has its own set of multipliers which are applied to the ones in the GRID section when the end of the EDIT section is reached (#4002).

55) Added a check that a keyword is valid for use with the PYACTION keyword before it is inserted into the deck (#4008).

56) Fixed the initialization of gas-water simulations with a transition zone (#5293).

B.1.5 KNOWN ISSUES

1) 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 (#3078). The work around is to plot the data in OPM ResInsight and right-click on the plot to view and copy the data.

2) 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.

3) 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.

4) 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.

5) 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)
```

6) 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.

7) 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.

8) 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*).

9) 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*).

10) Currently the OPERATER keyword in the EDIT section does not work with the DEPTH, TRANX, TRANY and TRANZ property arrays (*#2994* and *#748*).

11) 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*).

12) 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*).

13) 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*).

14) 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*).

15) **There is a unit handling issue associated with OPERATE keyword. If the OPERATE(X) parameter has units, as for example PERMX, then the conversion is always done in SI units, despite the input deck declaring the deck to be fields units, as per FIELD keyword in the RUNSPEC section. Note that OPM Flow performs all of its calculations internally in SI and performs unit handling only when inputting the *.DATA file and when outputting result files. Thanks to *lrijkels* for reporting the issue. See *#4597* for details.**

16) There is an issue associated with restarting from a restart file with the solution gas (Rs) maximum rate of increase, as defined by the DRSDT keyword in the SCHEDULE, that has been set to zero. This is because, the simulator does not save/restore this setting in simulator's restart files, which means that simulator misses the essential value zero upon restarting the case. As a work-around one can use the option *–sched-restart=true*, when running the restart case. This will initialize the restarted simulation based on information from the complete SCHEDULE section, instead of just the parts that we're going to simulate and the rest from the restart file. Thanks to *goncalvesmachadoc* for reporting the issue. See *#4272* for details.

17) OPM cannot be built with dune-fem version 2.9 or later (*#4934*). Please use a previous version.

18) The simulator uses an irregular corner-point grid geometry with adjusted pore volumes to represent radial grids so it is not possible to create a full ring (360 degree disk) with only one cell in the theta direction (NY=1). The work around is to model a slice (say DTHETA=60 degrees). Note that as the angle increases larger pore volume adjustments are required (*#4755*).

19) In some cases with the network option the simulator can wrongly report that a well has no THP constraints, for example

```
GLIFT WTEST: Well S-3H does not have THP constraints
```

when THP constraints have been defined (*#4887*).

20) Dispersion in the gas phase leads to convergence issues for the 11th SPE CSP (*https://spe.org/csp*) models Version 11B and Version 11C (and is not fully tested). Therefore dispersion in the gas phase has been temporarily removed and a warning added (*#5101*, *#859*).