APPENDIX B: OPM FLOW RELEASE HISTORY

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B.1   RELEASE 2023-04

This release is dedicated to the memory of Ove Sævareid, who regrettably passed away suddenly this April. Ove was a long-standing contributor to OPM, and active up to the last. We are thankful for his contributions to the OPM community. His enthusiasm, know-how and scientific expertise will be missed by colleagues and friends.

A major change for this release is the validation process, that now is more strict, in that all keywords that would effect the simulation results will now cause an error message resulting with the simulator terminating with an error. Previously, the simulator would issue a warning message instead, thus allowing the simulator to continue. A new command line parameter, *–parsing-strictness*, has been implemented to give better flexibility over the validation process. To restore the previous behavior, use *–parsing-strictness="low"*. This will allow unsupported keywords that would change the simulator results if supported, and even if marked critical, for the simulator to continue.

Note that Dune version 2.7 is now required.

The 2023-04 release consists of some new features and various improvements and bug fixes. Highlights for this release include:

- For gas-water systems, the simulator now supports Equilibrium Initialization using the EQUIL and associated keywords in the SOLUTION section.

- Added support to specify diffusion coefficients for CO2STORE cases using the DIFFCGAS and DIFFCWAT keywords for gas-water cases, thus allowing the CO2STORE option to be used with gas-water systems. Using CO2STORE for gas-oil systems, one still needs to use the DIFFC keyword.

- The simulator now supports the EDITNNCR keyword in the EDIT section.

- For two-phase gas-water systems, the hysteresis option is now supported.

- Added support for the commercial compositional simulator keywords GSF, that define the gas relative permeability and gas-water capillary pressure data as a function of gas saturation, and WSF that defines the water relative permeability as function of water saturation.

- Implemented support for the AQUFLUX keyword both in the SOLUTION and SCHEDULE sections.

- Added grid independent well specification using well trajectory data. The WELTRAJ keyword in the SCHEDULE section defines the well path and the COMPTRAJ keyword in the SCHEDULE section defines the well trajectory connections to the grid, that is the perforations intervals.

- The WRFTPLT keyword in the SCHEDULE section has been extended to include both Production Logging Tool ("PLT") data as well as multi-segment well data.

- Added support for writing out inter-block flows, including non-neighbor connection flows using the RPTRST(FLOWS) parameter, and inter-block flows at reservoir conditions using the RPTRST(FLORES) parameter, in both the SOLUTION and SCHEDULE sections.

For the 2023.04 release the opm-material module has been folded and merged into opm-common, as show in Figure B.1 This further simplifies building the simulator from source.
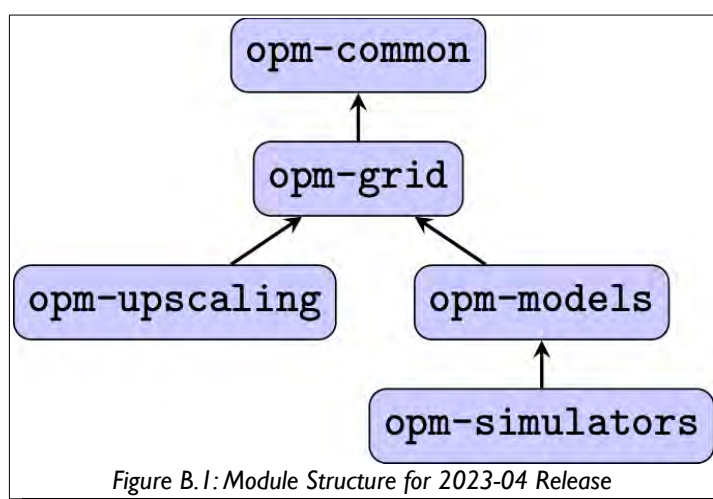
Figure B.1: Module Structure for 2023-04 Release

B.1.1 NEW AND DEPRECATED COMMAND LINE OPTIONS

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

No.	Variable Name	Description	Default
1	--cpr-reuse-interval	A positive integer that sets the reuse preconditioner interval. Used when $-cpr\text{-}reuse\text{-}setup$ is set to 4, then the preconditioner will be fully recreated instead of reused every N linear solve, where N is this parameter. The default has been increased from 10 to 30 (*#4338*).	30
2	--cpr-reuse-setup	A positive integer that defines if the CPR solver should re-use the AMG setup. Valid options are: 0 : Recreate the preconditioner for every linear solve. 1 : Recreate once every time step. 2 : Recreate if last linear solve took more than 10 iterations. 3 : Never recreate. 4 : Recreate every N linear solves, where N is the parameter --*cpr-reuse-interval*. Changed the default value from three to four (*#4338*).	4
3	--linear-solver-reduction	A real positive double precision value that sets the minimum reduction of the residual for the linear solver. The linear solver convergences when the residual is reduced sufficiently. **The simulator now overrides the default reduction to be 0.005 instead of 0.01, if the linear solver has been set to one of the cpr options, in a similar manner as how the default maximum number of linear iterations for the cpr and cprw options are changed to 20 instead of 100, unless specified by the command line option by the user** (*#4338*).	0.01

No.	Variable Name	Description	Default
	OPM Flow 2023-04 New And Deprecated Command Line Options		
4	--linear-solver	A defined quoted character string that sets the configuration of the linear solver, valid values are: 1) ilu0 (default), 2) cpr (an alias for cprw)[339][340] and [341] 3) cpr_quasiimpes, 4) cpr_trueimpes, 5) cprw, 6) amg,[342] 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. This option can also be invoked via the CPR keyword in the RUNSPEC section; however, the command line parameter takes precedence. 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'. 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 to configure a user specific linear solver JSON file. The default is "ilu0". **The option "cpr" now is an alias for "cprw" instead of "cpr_trueimpes".**	"ilu0"

[339] 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).

[340] R. Scheichl, M. Roland, J. Wendebourg, Decoupling and block preconditioning for sedimentary basin simulations, Computational Geosciences 7 (2003) 295{318.

[341] 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.

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

No.	Variable Name	Description	Default
	OPM Flow 2023-04 New And Deprecated Command Line Options		
5	--load-step	An integer value that determines if the simulator should load the serialized state from OPM Flow's version of the restart file. And should be set to either a specific report step, or 0 to load the last stored report step. The default value of -1 does not load the data from the OPM Flow specific restart file. OPM Flow's version of the restart file, is written using the *–save-step=N* option.	-1
6	--opencl-ilu-parallel	A Boolean value set to true or false that if set to true then parallelize the ILU decomposition and application on GPU, or not (false).	TRUE
7	--output-extra-convergence-info	Provides additional convergence output to separate files for diagnostic purposes. The available options are: 1) "none" results in no extra output and overrides all other options. 2) "steps" writes out convergence information per time step, to a *CASENAME.INFOSTEP* file. The file is useful for identifying numerical issues. 3) "iterations" writes out non-linear convergence metrics, i.e., the MB and CNV values, per phase, for each non-linear iteration in each time step, to a *CASENAME.INFOITER* file. Options may be combined with commas, e.g."steps,iterations" for multiple outputs. The default value of "none" prevents the two files from being written out, for better compatibility with the commercial simulator (*#4322*).	"none"

No.	Variable Name	Description	Default
8	--parsing-strictness	Set strictness of parsing process. Available options are: 1) "normal": stop for critical errors, and for unsupported keywords that would would change the simulator results if supported. 2) "high": stop for all errors, that is even for unsupported keywords that do not effect the results, for example ECHO and NOECHO. 3) "low": same as normal, except do not stop due to unsupported keywords that would change the simulator results if supported, and even if marked critical. Default: "normal" See #4607 and #4604 for details.	"normal"
9	--relaxed-linear-solver-reduction	A real positive value that defines the minimum reduction of the residual which the linear solver need to achieve for the solution to be accepted.	0.01
10	--save-step	A character string that determines if the simulator should save the serialized state of the OPM Flow simulator at one or more report steps to a special *.OPMRST file. This is in addition to the normal restart files written, and consumes significantly more space than the normal restart files, but restarting OPM Flow from this file using the *--load-step* option deviates less from the original run, compared to restarting using the normal restart features. The files produced are not compatible with other simulators, and also will not be compatible between different releases of OPM Flow The parameter should be set to one of the following: 1) "all" to save all report steps, 2) ":x" to save every x'th step, or 3) "x" to save a specif time step. The default value of "" does not write anything to the OPM Flow specific restart file.	""
11	--cpr-max-ell-iter	A positive integer that sets the maximum number of Iterations for the elliptic pressure part of the Constrained Pressure Residual ("CPR") solver. Depreciated (#4338).	20

No.	Variable Name	Description	Default
OPM Flow 2023-04 New And Deprecated Command Line Options
12	--ecl-strict-parsing	A Boolean value set to true or false that switches on (true) or off (false) strict parsing mode for parsing - all errors are collected before the application exists. Useful for debugging initial runs. Depreciated (#4607 and #4604).	FALSE
13	--separate-sparse-source-terms	Note that the *--separate-sparse-source-terms* is only available when running the *--flow_blackoil* simulator, not the main simulator, *flow*. It is therefore not possible to change it when running *flow*, and the default will always apply (the default is to keep existing behavior). This is because the feature is experimental, but may be incorporated at a later day into *flow* after sufficient testing. To use the experimental *--flow_blackoil simulator* one must build OPM from source (#776 and #4347).	

Notes:

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

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

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

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

Table B.1: OPM Flow 2023-04 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) Implemented support for the AQUFLUX keyword both in the SOLUTION and SCHEDULE sections (*#3378*, *#4429* and *#4480*).

2) Added support for dissolved gas in water with OPM Flow specific keyword DISGASW in the RUNSPEC section, for use with the CO2STORE model and gas-water systems. The formulation incorporates diffusion. However, currently only standard wells are supported, but multi-segment wells support is ongoing, as well as implementation of the RSW keyword in the SOLUTION section to define the initial gas solubility in water ratio (*#3217*, *#4292*, *#763* and *#3246*).

3) Added support for vaporized water to the gas phase in the CO2STORE- BRINE model. The PVT properties are assumed to be independent on the water content (*#3404*).

4) The Thermal model can now be used with gas-water systems, including with the CO2STORE model, to support temperature dependent properties. Currently, this is implemented as a standalone simulator, but will eventually merged into OPM Flow (*#4482*).

5) Added parser support for the following keywords: GASWAT, COMPS, HWELLS, SOLID in the RUNSPEC section, CNAMES, NCOMPS and ZMFVD in the PROPS section, FIELDSEP in the SOLUTION section, and WELLSTRE and WINJGAS in the SCHEDULE section (*#3442*).

6) Implemented support for the CPR keyword in the RUNSPEC section, that invokes the Constrained Pressure Residual linear solver. When used in the RUNSPEC section the keyword is equivalent to using the command line parameter *--linear-solver= "cprw"*. Note that if the command line *–linear-solver* parameter has been used, then this will take precedence over the CPR keyword in the RUNSPEC section (*#4400*).

7) Added support for using the Damaris library (*#4309*, *#4432*, *#4414*, and *#4481*). See also *#4399* for a bug fix.

   Damaris is a middle-ware for asynchronous I/O and data management targeting large-scale, MPI-based High Performance Computer ("HPC") simulations. Initially the software used dedicate cores for asynchronous I/O in multi-core nodes of HPC platforms, with an emphasis on ease of integration in existing simulations, efficient resource usage (with the use of shared memory) and simplicity of extension through plug-ins. Over the years, the software has evolved into a more elaborate system, providing the possibility to use dedicated cores or dedicated nodes to carry out in situ data processing and visualization. It proposes a seamless connection to the *VisIt visualization framework* to enable in situ visualization with minimum impact on run time. Damaris provides a simple API and can be easily integrated into the existing large-scale simulations (*Damaris*).

8) Added support to specify diffusion coefficients for CO2STORE cases using the DIFFCGAS and DIFFCWAT keywords for gas-water cases. Using CO2STORE for gas-oil systems, one still needs to use the DIFFC keyword. Note that if neither the DIFFCGAS and DIFFCWAT keywords are declared when the DIFFUSE keyword is active, then the simulator will use default values computed based on temperature and pressure in the reservoir using correlations in the literature (*#3455*).

9) Added ISTL linear solver 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 (*#4269*).

10) The simulator now supports the EDITNNCR keyword in the EDIT section (*#4600*, *#4578* and *#3459*).

11) Added the flexiblegmres linear solver, similar to bicgstab (the default linear solver), and gmres that were already available. The flexiblegmres solver is a variant of the gmres algorithm but allows changes in the preconditioning at every step in the iterative process (*#4564*).

12) Added Energy support for two-phase gas-water systems (*#4574*).

13) Previously for gas-water systems, only Enumeration Initialization was available. The simulator now supports Equilibrium Initialization using the EQUIL and associated keywords in the SOLUTION section (*#4316*). See also *#4372* that changed the reported pressures for gas-water systems to the gas phase pressures, in order to be compatible with the commercial simulator.

14) For two-phase gas-water systems, the hysteresis option is now supported (*#3451*).

15) Added grid independent well specification using well trajectory data. The WELTRAJ keyword in the SCHEDULE section defines the well path and the COMPTRAJ keyword in the SCHEDULE section defines the well trajectory connections to the grid, that is the perforations intervals. WELTRAJ defined wells <u>must</u> use the COMPTRAJ keyword to define the connections to the grid, that is one cannot use COMPDAT for these type of wells. Secondly, the WELSPECS(I) and the WELSPECS(J) parameters must be defaulted with I*, for these type of wells (*#3384* and *#3466*).

16) Added support for the commercial compositional simulator keywords GSF, that define the gas relative permeability and gas-water capillary pressure data as a function of gas saturation, and WSF that defines the water relative permeability as function of water saturation. The keywords should only be used if only the gas and water phases are present in the run, and can therefore also be used with the CO2STORE model (*#3406* and *#4485*).

17) Added support for directional relative permeabilities with hysteresis, using the IMBNUMX, IMBNUMY, and IMBNUMZ keywords in the REGION section. Note that the SATOPTS(IRREVERS) parameter in the RUNSPEC section, that sets the relative permeability assignment to non-reversible, and results in different sets of relative permeability tables being applied for flow from the x_i to x_{i+1} direction and the x_i to the x_{i-1} direction, for all directions (x, y, z), is currently <u>not</u> supported. To be clear, the IMBNUMX-, IMBNUMY-, and IMBNUMZ- keywords are currently not supported (*#3364* and *#4384*).

18) Added support for the GPU rocsparseSolver, the feature is experimental and will require a certain kind of GPU, not a usual consumer one. Use the *–help-all* command line parameter to see the available options (*#4178* and *#4406*).

19) The OPM Flow specific keyword RWGSALT has now been implemented. The keyword defines the relationship of water vaporization versus pressure and salt concentration, for when the VAPWAT keyword has be declared in the RUNSPEC section indicating that vaporized water is present in the gas phase. In addition, RWGSALT may also be used if the Salt Precipitation model has been activated via the BRINE and PRECSALT keywords in the RUNSPEC section (*#4189*, *#3187*, *#744* and *#538*).

20) Added support and implementation of salt density on the OPM Flow SALTSOL keyword in the PROPS section. The keyword originally defined a grid block's maximum salt solubility for each PVTNUM region, and now supports in addition the salt density for the grid blocks (*#745* and *#2981*).

21) Implemented support for the CVIR, well connection reservoir volume injection rate, and CVPR, well connection reservoir volume production rate (*#4370*).

22) Added various variables for OPM Flow's black-oil CO2STORE Model, that are based on the commercial simulator's compositional vectors, as the CO2STORE model is only available in the commercial simulator's compositional simulator (*#3408* and *#4477*).

23) Added multi-segment well segment vaporized oil rate (SOFRF) and dissolved gas rate (SGFRF) SUMMARY vectors (*#4252* and *#3215*).

24) Added vaporized water (VAPWAT) to two-phase Gas-Water formulations, together with exporting the vapor phase mole factions to the restart file (YMFWAT). In addition, use the correct molar mass for liquid phase mole fractions of CO_2 (that is, the mole factions of CO_2 in the water phase) when converting and writing out liquid phase mole fractions (XMFCO2) to the restart file (*#4537*).

25) Previously, the WRFTPLT keyword in the SCHEDULE section only wrote the standard RFT data set (pressure and fluid saturations versus depth) for the connected grid blocks, the same as the WRFT keyword in the SCHEDULE section. The keyword has now be extended to include both Production Logging Tool ("PLT") data as well as multi-segment well data (*#3151*, *#3173*, *#3179*, *#3184*, *#3145*, *#3155*, *#4261*, *#4168* and *#4180*).

B.1.3 IMPROVEMENTS

Improvements include:

1) The OPM Flow BC keyword that sets the model's boundary conditions in the SOLUTION section, has been extended to include DIRICHLET boundary conditions, to enable user defined boundary conditions to be defined. In addition, the BC(PRESS) and BC(TEMP) parameters have been added to allow the simulator's equilibrium calculated values at the boundary to be used, if these two parameters are defaulted. Note that BC keyword syntax and structure is likely to changed in future releases of the simulator (*#739*, *#3185*, *#3212* and *#4182*).

2) The OPM Flow BC keyword using the DIRICHLET boundary conditions has been extended with the THERMAL option. The temperature is kept constant at the given boundary by allowing for heat conduction only. In other words no fluid flow only heat (*#3457* and *#4562*).

3) The OPM convertECL utility program converts various commercial simulator and OPM Flow generated output files to various other formats, as well as being able to list and extract data from user supplied time steps. The utility has now been extended with -g option, that will output GRDECL files[343]. In this case the input file should be formatted or unformatted simulation files. The -o option can be used to specify output file name and is only valid with -g option. The program requires the input name of file to be converted, if this is a binary file the output is a formatted, and vice versa. The current options include:

```
-h Print help and exit.
-l List report step numbers in the selected restart file.
-g Convert file to grdecl format.
-o Specify output file name (only valid with grdecl option).
-i Enforce IX standard on output file.
-r Extract and convert a specific report time step number from a unified restart
file.
```

Use the -help option to get further details on the program's features (*#3201*).

4) Improved the Distributed Well code base by supporting variable length connection data for this type of formulation (*#4201* and *#599*).

5) Dune version 2.7 is now required (*#376*, *#631*, *#788*, *#3414*, and *#4490*).

6) Previously, when increasing and allocating the artificial lift quantity (ALQ), if a given ALQ value resulted in a well's rate being invalid, then the simulator stopped allocating additional values of ALQ. Now the simulator continues to increase and allocate ALQ values with the intention that higher ALQ values may allow the well to flow again. At the same time the simulator checks that rate limits are not violated (*#4571*).

7) Improved gas lift optimization allocation for wells under gas lift and group control (*#4214*).

8) OPM Flow now applies the grid unit transformation when writing out the EGRID file (*#3233*).

9) Improved the methodology for the ILU preconditioner by only copying the data, and avoiding the need for allocation and matrix construction, when the matrix already exists and has the correct sparsity structure. Expected performance gain for the linear solver setup part for ILU0 is estimated be approximately 15% based on the Norne model using eight processors (*#4427*).

10) Improved the handling on how the simulator reads left-handed grids, that fixes some of the problems previously experienced with with this type of grid. There is no guarantee that this improvement will solve this particular problem, however; but if a user previously experienced this problem, then they should re-test the model with this release. If this release does not fix the issue then please report this via GitHub, together with an example model showing the failure (*#625*).

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[343] *GRDECL files is the extension commonly used for exporting the commercial simulator array data in fixed format by earth modeling software. These type of files include the keyword followed by the data, and can be directly loaded into both OPM Flow and the commercial simulator.*

11) The OPM Flow specific keyword MINPVFIL has now be depreciated, the keyword has not been documented in the manual, and has not been used for a long time (#3461).

12) Improved the error reporting for when the fault name was not found in the MULTFLT keyword, that is MULTFLT(FLTNAME) contains a fault that has not be defined by the FAULTS keyword. Previously, the error message was:

```
Applying MULTFLT in MULTFLT.DATA line 237

Error: [./src/opm/....../EclipseState/EclipseState.cpp:380] Could not set fault
transmissibility multiplier 0 for fault FAULT01: Key FAULT01 not found.

Error:
An error occurred while creating the reservoir properties
Internal error: [./src/opm/input/eclipse/EclipseState/EclipseState.cpp:380] Could
not set fault transmissibility multiplier 0 for fault FAULT01: Key FAULT01 not
found.

Error: Unrecoverable errors while loading input:
[./src/opm/input/eclipse/EclipseState/EclipseState.cpp:380] Could not set fault
transmissibility multiplier 0 for fault FAULT01: Key FAULT01 not found.
```

And now the new error message is:

```
Applying MULTFLT in MULTFLT.DATA line 237

Error:
MULTFLT: Cannot set fault transmissibility multiplier
MULTFLT(FLTNAME) equals FAULT01 and MULT(FLT-TRS) equals 0
Error creating reservoir properties: Key FAULT01 not found.

Error:
An error occurred while creating the reservoir properties
Internal error: Error Processing MULTFLT
```

See #3077 and #3062 for details.

13) Added additional time step convergence reporting of MB and CNV quantities per iteration, intended for diagnostic and analysis purposes. The data will not be written out to the CASENAME.INFOITER file unless specifically requested via the *--output-extra-convergence-info* command line parameter.

ReportStep	TimeStep	Time	Iteration	MB_Oil	CNV_Oil	MB_Water	CNV_Water	MB_Gas	CNV_Gas	WellStatus
82	0	9.1200e+02	0	2.3292e-05	4.5453e-02	1.1772e-05	2.5904e+01	9.7696e-06	1.9537e-02	CONV
82	0	9.1200e+02	1	1.5357e-07	2.4792e+00	3.6332e-06	4.1195e+00	1.8721e-07	2.9106e+01	CONV
82	0	9.1200e+02	2	3.8775e-07	6.7989e-01	3.1721e-06	1.1337e+00	3.2625e-07	3.9179e+00	CONV
82	0	9.1200e+02	3	2.3706e-07	2.1720e-01	3.3442e-06	9.9475e-01	1.8359e-07	2.7495e-01	CONV
82	0	9.1200e+02	4	8.0505e-08	1.3516e+00	3.2876e-06	7.8305e-02	1.0693e-07	4.7519e-01	CONV
82	0	9.1200e+02	5	2.3315e-08	9.0378e-03	2.7611e-06	8.3702e+00	3.4747e-08	2.3653e-02	CONV
82	0	9.1200e+02	6	1.8666e-08	3.0498e-03	2.6078e-06	7.1568e-01	2.5702e-08	1.0469e-03	CONV
82	0	9.1200e+02	7	8.2979e-09	1.2817e-03	9.1366e-07	6.9700e-02	4.8841e-09	7.1927e-04	CONV
83	0	9.1300e+02	0	3.2710e-05	2.3169e-01	1.6583e-05	2.4644e-01	1.3703e-05	2.4830e-01	CONV
[...]										
83	0	9.1300e+02	1	2.2321e-07	6.9474e-02	5.0324e-06	1.5035e-01	2.1392e-07	6.8448e-02	CONV
83	0	9.1300e+02	2	7.9707e-08	1.7758e-02	4.5233e-06	1.4823e+01	1.8688e-08	8.4370e-02	CONV
83	0	9.1300e+02	3	7.1908e-08	1.0376e-03	4.4680e-06	1.6808e+00	1.2909e-08	2.3520e-03	CONV
83	0	9.1300e+02	4	1.5509e-08	6.7821e-05	2.0725e-06	3.0567e-02	7.7076e-09	5.2698e-04	CONV
83	0	9.1300e+02	5	1.4586e-11	1.4220e-05	2.3775e-07	4.4014e-05	2.7961e-10	6.3101e-06	CONV
[...]										
[...]										
120	1	2.5105e+03	4	1.9859e-08	6.5491e-04	8.7468e-06	1.0563e-03	5.3570e-08	7.6632e-04	CONV
120	1	2.5105e+03	5	1.7167e-10	5.7449e-03	1.3679e-07	5.5678e-04	2.8410e-09	4.9974e-03	CONV
121	0	2.5560e+03	0	4.4468e-06	1.1437e-03	1.6915e-06	1.3708e-03	2.9207e-06	1.3201e-03	CONV
121	0	2.5560e+03	1	1.1517e-09	5.9272e-06	4.1542e-07	4.1135e-05	1.3881e-09	3.1044e-06	CONV
121	0	2.5560e+03	2	5.0131e-12	1.3745e-08	3.7373e-08	4.7599e-06	8.0810e-12	1.8838e-08	CONV

Figure B.2: INFOITER Convergence Report Example

See #4312, #4311, #4322, and #4323 for further details.

14) Improved numerical performance of the tpfalinearizer routine by using direct access to matrix elements in the routine, that is, instead of using matrix[row, col] to access the matrix block to be
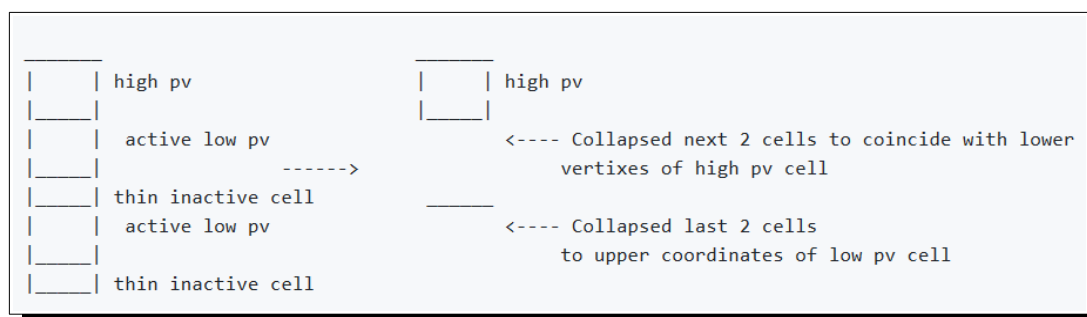
modified, the code now stores the pointers to the relevant block. Thus, avoiding a search on the relevant row to find the correct block matching the requested column number. The change gives a speedup of approximately 10% for this part off assembly code. This, together with not using local well assembly, will further increase numerical performance (*#770*).

15) Recent testing on a large full field ensemble model has led to improvements in the default CPR parameters used by the simulator, including, combining a number of minor adjustments for simpler and more consistent and robust use of the CPR options. Changes include:

   a) Removed two unused command line parameters, --*cpr-ell-solvetype* and --*cpr-max-ell*. The former was never used and the latter was not used correctly, as it should should have changed the maximum iterations of the coarse solver, not the repeats of the preconditioner, and should now be used instead with the JSON file input.

   b) Made the default AMG parameter setup for the *cpr* (including *cpr_trueimpes* and *cpr_quasiimpes*) option of the command line parameter --*linear-solver*, match the setup for *cprw*. In particular, beta = 0.0 (not 1e-4) and prolongationdamping = 1.0 (not 1.6).

   c) The simulator now overrides the default reduction to be 0.005 instead of 0.01, if the linear solver has been set to one of the cpr options, in a similar manner as how the default maximum number of linear iterations for the cpr and cprw options are changed to 20 instead of 100, unless specified by the command line option by the user.

   d) Changed the default value for --*cpr-reuse-setup* to 4 (was 3). The old default never recreates the preconditioner from scratch, i.e. the hierarchy that is built for AMG is kept unchanged (the numbers in the matrices and therefore also smoothers etc. are updated every solve). The new default will recreate it every --*cpr-reuse-interval* solves instead. The default for --*cpr-reuse-interval* has been increased from 10 to 30 (but recall the interval was essentially infinite when --*cpr-reuse-setup* was 3).

   See also B.1.1 New and Deprecated Command Line Options for details (*#4338*).

16) Refactored the handling of PINCH and MINPV keywords in preparation to support more of the PINCH test cases. Previously, the logic on how to detect inactive cells would not work correctly if the ACTNUM array was empty. This now been fixed. The PINCH(PINCHOPT) parameter controls the generation of pinch-outs when the MINPV keyword has been used to deactivate cells with small pore volumes. Only the default value of GAP is supported that allows for the generation of Non-Neighbor Connections (NNCs) across cells that have been made inactive with the MINPV keyword when the pinch-out threshold thickness, PINCH(PINCHTHK), is greater than the cells thickness.

   For example, given two active cells that get deactivated via the PINCH keywords, would result in:

```
 _____                      _____
|     | high pv              |     | high pv
|_____|                      |_____|
|     |  active low pv                     <---- Collapsed next 2 cells to coincide with lower
|_____|            ------>              vertixes of high pv cell
|_____| thin inactive cell    _____
|     |  active low pv                     <---- Collapsed last 2 cells
|_____|                                    to upper coordinates of low pv cell
|_____| thin inactive cell
```

   Another example, with an additional bottom cell at the base, would result in:

```
|      | high pv         |      | high pv
|_____|                  |_____|
|     |   low pv         |     |  <---- Collapsed next 4 cells to coincide with lower
|_____|           ------>|     |        vertixes of high pv cell and extended the next
|_____| thin cell        |     |        cell to add the volum of the pinched layers.
|     |   low pv         |     |
|_____|                  |     |
|_____| thin cell        |     |
|     |                  |     |
|_____| high pv          |_____|
```
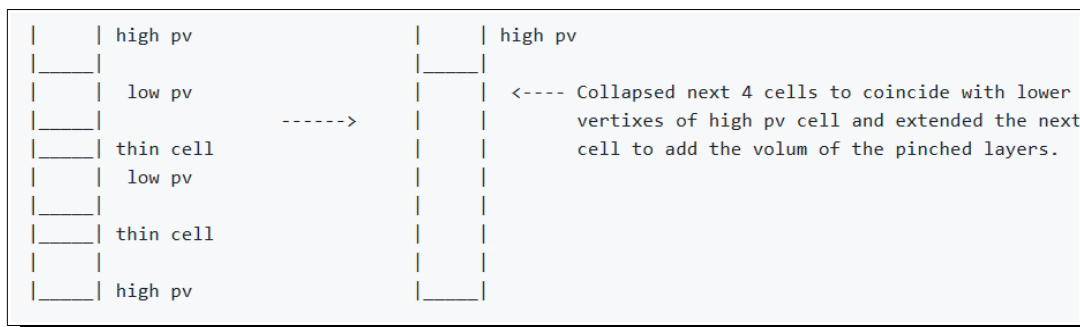
See *#639* for details.

17) Improved input checking of keywords and keyword options so that in general, unsupported keywords which effect the results, will cause the simulator to issue an error message and to stop.

```
Error: Unsupported keywords or keyword items:

  SKIP: keyword not supported
  In file: TEST1.DATA, line 147

  ENDSKIP: keyword not supported
  In file: TEST1.DATA, line 149
```

However, keywords, that do not influence the result, for example: DEBUG, ECHO, NOECHO and RPTSOL etc., will result in a warning message and the simulation will continue.

```
Warning: Unsupported keywords or keyword items:

  RPTGRID: keyword not supported
  In file: TEST1.DATA, line 120

  NOECHO: keyword not supported
  In file: TEST1.DATA, line 132
```

Secondly, if an unsupported keyword parameter influences the results, for example WECON(WGR), then the simulator will now stop with an error message. Previously, the simulator would issue a warning message and continue (*#4278*).

18) The restart file's enumeration of active cells connected to analytic aquifers follows a column-based scheme. Recent work on compatibility prompted by real field models with the constant flux analytic aquifer type, has shown that the enumeration of the columns also must account for the horizontal model dimension. If $DIMENS(NX) \geq DIMENS(NY)$, then the columns are enumerated with the J index cycling faster than the I index. On the other hand, when $DIMENS(NY) > DIMENS(NX)$ the I index is supposed to cycle more quickly than the J index. Thus, we now guarantee that the innermost loop is always across the model layers, while ensuring that the 'outer' loop always iterates over an index range that is at least as large as that of the 'middle' loop (*#3409*).

19) For runs using the CO2STORE option, the simulator now unconditionally writes out the cell pressures to the restart file (*#4540*).

20) The simulator already supports constant flux aquifers (AQUFLUX keyword) entered both in the SOLUTION and in the SCHEDULE sections. Support is now extended to read and write the data to the restart file, compatible with the commercial simulator restart file.

The primary structural change is that we have to support analytic aquifers being introduced dynamically, whence the connection information (xCAQ) must be captured without knowing the full set of analytic aquifers. We therefore allocate those output arrays purely from the maximum sizes

entered in the RUNSPEC section whereas we defer determining the maximum aquifer ID to the point of capturing the dynamic values (*#3423*, *#3424* and *#3437*).

21) Improved RESTART file support by writing out inter-block flows, including non-neighbor connection flows using the RPTRST(FLOWS) parameter, and inter-block flows at reservoir conditions using the RPTRST(FLORES) parameter, in the SOLUTION and SCHEDULE sections (*#758*, *#3224*, and *#4275*). In addition, fixed a regression (issue *#4428*) associated with the implementation (*#4430* and *#781*).

22) When using *–load-step* to restart from a *.OPMRST file, the simulator will now check for the *.OPMRST file to be loaded in both the input file directory and the output file directory (*#4478*).

23) Added support for the molar fraction of CO_2 in brine array to be written to the RESTART file. The output only occurs if CO2STORE and DISGASW keywords are present in the RUNSPEC section, and the command line parameter, -enable-opm-rst-file is set to true (*#4529*, *#4535*, *#3449* and *#3448*).

24) Improved restart capability associated with well perforation data, by storing previous well states on the RESTART file (*#4479*).

25) Improved the writing out the restart file using the *--enable-opm-rst-file=true* command line option by adding additional checks to improve consistency (*#4613* and *#4606*).

26) The base arrays written to the restart file are compatible in both name and interpretation to those emitted in the SOLUTION section from other simulators, whereas the extended arrays are specific to OPM Flow. Added a tag to the extended arrays as OPM_EXTENDED instead of AUXILIARY as the latter is deprecated and will be removed at some point in the future. Also re-tag the TEMP array as OPM_EXTENDED when not required for thermal simulations and add support for the per-phase fluid density via the RPTRST request keys (DENx, with x being O, G, or W), in addition to the collective key DEN that the simulator already supports (*#4533* and *#4530*).

27) The rock fraction is usually taken as $1-PORO$, but if the pore volume has been adjusted using the PORV keyword, to effectively modify the porosity, $PVMULT*PORO$, then the rock volume will be incorrect. The simulator now applies the same PORV multiplier ($PVMULT$) to the rock fraction, that is, $PVMULT*(1-PORO)$. This is to avoid negative rock volume for $PVMULT*PORO>1$. See *#795* for details.

28) Improved the surface rate computation by restricting the values of Rs and Rv used in the calculation, to lie in the range of zero to the maximum known values of Rs and Rv (*#4335*).

29) Improved the error messages for multi-column keywords (SWOF, etc.), for when a column of data must be monotonically increasing or decreasing. Previously if there was an error, then the message would be of the form:

```
Error:
An error occurred while creating the reservoir properties
Internal error: Incorrect ordering of values in column: SW

Error: Unrecoverable errors while loading input: Incorrect ordering of values in
column: SW
```

Making it difficult to isolate the cause of the error. Now the message will be of the form:

```
Error:
An error occurred while creating the reservoir properties
Internal error: Non-monotonic values in keyword SWOF, at row: 11.
SW need to be entered in strictly increasing order.

Error: Unrecoverable errors while loading input: Non-monotonic values in keyword
SWOF, at row: 11.
SW need to be entered in strictly increasing order.
```

See *#3391* for details.

30) Improved reporting by printing the inter-region threshold pressures set via the THPRES keyword in the SOLUTION section. The simulator now prints the following report.

```
LIST OF ALL NON-ZERO THRESHOLD PRESSURES
----------------------------------------

    FLOW FROM REGION    TO REGION    THRESHOLD PRESSURE
    ----------------    ---------    ------------------
          1                 2            0.588031        BARSA
          1                 3            0.787619        BARSA
          1                 4            7.00083         BARSA
    ----------------    ---------    ------------------
```

See #4505 and #3422 for further information.

31) Currently, the simulator adds the source terms cell by cell, and when a perforated cell is reached, all wells and perforations are iterated over to find the correct term to add. So with K total perforations, the process takes approximately K^2 of amount of work. Using a new experimental feature, the simulator treats the well source terms separately, iterating over all wells and perforations just once, so now the process takes K amount of work. The difference for the assembly performance is modest: ~3% improvement observed with SPE9, which has a fairly high number of wells for its size. However, there are more opportunities that can improve performance, for example, using a similar approach for aquifers may give a similar boost in performance. The feature is activated by the command line parameter *--separate-sparse-source-terms* set to true (#776 and #4347).

Note that the *--separate-sparse-source-terms* is only available when running the *flow_blackoil* simulator, not the main simulator, *flow*. It is therefore not possible to change it when running *flow*, and the default will always apply (the default is to keep existing behavior). This is because the feature is experimental, but may be incorporated at a later day into *flow* after sufficient testing (#776 and #4347).

32) Re-factored the friction pressure calculation for multi-segment wells to make the code more robust (#4251).

33) Support for User Defined Quantities, UDQ variables, for multi-segment well segments (SU* SUMMARY vectors) has been implemented (#3235).

34) Improved the treatment of production wells controlled by zero rate and STOPPED wells. The issue was, although the simulator calculated rates very close to zero, the water cut and GOR values where spurious and random, due to the non-zero flow rates. Now the simulator sets the rate to zero during the initialization (from well state) at the beginning of each time step iteration, as well as the update process during the Newton solution of the wells (#4531).

35) Improved the handing of production wells when switching to THP control, that should help remedy the premature shutting of the production wells under these circumstances (#4409).

36) For wells under zero rate control, including STOPPED wells, the THP is now set to zero (#4563).

37) Given the following SCHEDULE section keywords:

```
WCONPROD
  'PROD-2'   'SHUT'  'RESV'  4*  0.0 1.0 1* 0 1.0 5* /
/

DATES
 1 'FEB' 2000 /
/

WELOPEN
  'PROD-2' 'OPEN'  5* /
/

WELTARG
   'PROD-2' 'RESV'  2000.0 /
/

-- 31.000000 days from start of simulation ( 1 'JAN' 2000 )
DATES
 1 'JUN' 2000 /
/
```

Previously, the simulator would not open the well PROD-2 with the WELOPEN keyword, since the well PROD-2 disallows cross-flow and also has a zero rate constraint. And WELOPEN does not consider the later WELTARG keyword is changing the rate constraint to be non-zero. Now the simulator will allow WELOPEN to open the well without checking the rate constraint and cross-flow specification. Secondly, the behavior is similar to how the simulator treats the WCON*** keywords, in that that the simulator does not check the rate constraint and cross-flow setup; whereas, checking the rate constraint and cross-flow setup only for the WELOPEN keyword, is introducing an inconsistency (*#3463*).

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

No.	Summary Keyword	Comment
1	CVIR and CVPR	Implemented support for the CVIR, well connection reservoir volume injection rate, and CVPR, well connection reservoir volume production rate (*#4370*).
2	FGCDI, FGCDM, FWCD, FWIPG, FWIPL, RGCDI, RGCDM, RWCD, RWIPG, and RWIPL	Added various variables for OPM Flow's black-oil CO2STORE Model, that are based on the commercial simulator's compositional vectors, as the C02STORE model is only available in the commercial simulator's compositional simulator (*#3408* and *#4477*).
3	SGFRF and SOFRF	Added multi-segment well segment vaporized oil rate (SOFRF) and dissolved gas rate (SGFRF) SUMMARY vectors (*#4252* and *#3215*).
4	FGIPL and RGIPL	Added gas in-place in the liquid phase, only for cases that have dissolved gas in the water phase (*#4551*).

Table B.2: New SUMMARY Keywords for the 2023-04 Release

B.1.4 BUG FIXES

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

1) Fixed a bug with AQUCT and AQFETP keywords that resulted in only the last entry of the keywords being active int run. Now all occurrences are taken into consideration (*#3469* and *#3468*). Currently work is on going to implement analytical aquifers in the SCHEDULE section via the AQUCT and AQUFETP keywords, until this work is complete, the simulator will issue an error message if the keywords are found in the SCHEDULE section, in order to avoid incorrect results (*#3469*, *#3468* and *#3397*).

2) In degenerate geometries, that is when a three-dimensional grid cell is essentially flat, or it may have three or two-dimensional coordinates but be essentially a line in space, then the grid cell face may reduce to a line. In this case the area of the cell is zero and dividing by the total area leads to centroids with NaN coordinates. This scenario has now been fixed by using the 'inpoint', which is typically the arithmetic average of the face's vertex coordinates (*#624*).

3) Fixed two bugs there were noticed during close inspection of the code. The first bug was associated using the mass fraction instead of the mole fraction, and the second was a sign error in the thermal Brine density calculations. Thanks to *@svenn-t* for noticing the sign bug (*#3452*).

4) Fixed a bug introduced with *#4292* for when both VAPWAT and DISGASW keywords are active in the RUNSPEC section (*#4342*).

5) Fixed an issue when the CO2STORE keyword is combined with a two phase gas-water system using Carter Tracy aquifers (*#4580*).

6) Corrected a regression with the Damaris implementation introduced with commit *#4396*, which has now been fixed with *#4399*.

7) There was an issue with writing out the summary ESMRY files when two (or more) concurrent simulations were run in the same folder. Occasionally, this caused the temporary export file (TMP_.ESMRY) to be simultaneously accessed by more than one run, which resulted in errors in writing out the file. The temporary export file name has now been updated to include both root name and seconds since epoch, to resolve the issue (*#3202*).

8) OPM Flow's support for Field-Programmable Gate Array ("FPGA")[344] devices is deprecated due to currently not functioning correctly (*#4271*).

   A FPGA is an integrated circuit that consists of internal hardware blocks with user-programmable interconnects to customize operation for a specific application. The interconnects can readily be reprogrammed, allowing an FPGA to accommodate changes to a design or even support a new application during the lifetime of the part.

9) Fixed a bug associated with gas lift optimization for parallel runs. Now group controls and constraints are fully implement in stage two optimization, and information is communicated to all nodes (*#4310*).

10) Fixed a bug in re-calculating the gas lift gradient at stage two of the gas lift calculation (*#4573*).

11) Previously, the simulator did not correctly support the GCONINJE(VREP) option, that controls the voidage replacement ratio, if the group contained multiple subgroups with both water and gas injectors. This has now been fixed by correctly calculating the group reduction rate (i.e., the total rate of wells not under group control but in the group), and also for sub-groups (*#4460*).

12) For the GCONPROD(ACTION) parameter in the SCHEDULE, only the RATE options is supported by the simulator. The simulator will now issue an error message, if GCONPROD(ACTION) is set to a value other than RATE (*#4593* and *#4595*).

---

[344] *A FPGA is an integrated circuit that consists of internal hardware blocks with user-programmable interconnects to customize operation for a specific application. The interconnects can readily be reprogrammed, allowing an FPGA to accommodate changes to a design or even support a new application during the lifetime of the part.*

13) Fixed an issue with the GPMAINT keyword, when GPMAINT(FIPNUM) parameter had been set to zero for setting the pressure maintenance for the whole field (*#4259*).

14) Previously, if the GPMAINT keyword was used without the GCONPROD and GCONINJE keywords, then the simulator would throw an exception. This has now been corrected, such that simulator will now proceed as normal if the GPMAINT keyword is active, but the GCONPROD and GCONINJE keywords are not active or present in the deck (*#4359*).

15) Fixed a bug with the group control output to the terminal, so that the last group control is now correctly reported (*#4235*).

16) Disabled HDF5 compression if the version of HDF5 is less than or equal to 1.8, as compression for these versions does not work, especially on Red Hat 7 systems (*#4534*).

17) Fix a regression caused by pull request *#3364*, associated with the JFUNC keyword, used to scale oil-water capillary pressure (*#3403*).

18) Some build issues on macOS have been addressed (*#3385*).

19) If the MINPV keyword was used without the PINCH keyword, the simulator silently assumed that the PINCH(PINCHOPT) parameter was set to "PINCH GAP", when processing MINPV. Thus, the simulator would generate Non-Neighbor Connections ("NNC"), where none should have been created. Secondly, when one cell was deactivated the simulator missed checking whether the thickness of this cell was below the threshold, as set with the PINCH(PINCHGAP) parameter, for when PINCH(PINCHOPT) is equal to "PINCH NOGAP", before creating an NCC over it. Both issues have now been addressed (*#622*).

20) Using the MULTFLT keyword at the start of the SCHEDULE section resulted in the simulator throwing an exception. This has now been fixed (*#761*).

21) Previously, only the last MULTREGP keyword in the input deck was processed, instead of all occurrences of the keyword. This has now been corrected by processing all MULTREGP keywords (*#3395*).

22) Previously, using the MULTZ- keyword to adjust the vertical transmissibility (TRANZ) was not honored, and was completely ignored when calculating TRANZ combined with the PINCH keyword in the GRID section. This has now been rectified such that MULTZ- now behaves the same as the MULTZ keyword (*#4320*).

Note that OPM Flow does not require the GRIDOPTS(TRANMULT) parameter in the RUNSPEC section to be set to YES, in order to use this and other negative directional dependent multiplier keywords in the input deck. Whereas, the commercial simulator will terminate with an error if the keyword is present, and the GRIDOPTS(TRANMULT) parameter has not been set to YES.

23) The NODEPROP keyword in the SCHEDULE section, that defines the node properties for the Extended Network model, had an issue if the keyword was repeated for the same node, NODEPROP(NODE). If this occurred then the second, and subsequent NODEPROP keywords, would be ignored. This has now been rectified (*#3377*).

24) If a numeric aquifer defined by the AQUNUM keyword had no connections defined on the AQCON keyword, that connects numeric aquifers to the grid, then the simulator would throw an exception and stop. Now the simulator will issue a warning message and continue (*#3196*).

25) Previously, the porosity and permeability salt precipitation tables, as defined by the PERMFACT keyword in the PROPS section, were incorrectly allocated to the grid blocks using the EQLNUM array instead of the PVTNUM array. This has now been rectified (*#3349*).

26) If the gap created by pinched out cells is larger than the threshold, set via the PINCH(PINCHGAP) parameter, then the simulator would create Non-Neighbor Connections (NNCs). This has now been fixed by preventing of NNCs under these circumstances (*#3456*).

27) Previously, during processing the PINCH keyword, the simulator would compute the index of a cell in the next non-existing layer and sometimes would index cells which have ACTNUM set to zero or

zero thickness, thus creating an index out of bounds error. Secondly, when processing a cell at the bottom of the grid, then there should be no lower neighbor for a Non-Neighbor Connection. Both issues have now been addressed (*#650* and *#649*).

28) Fixed a regression that caused the print header not to be printed in the *.PRT file (*#4418*).

29) Fixed an issue with dune-fem and quad precision (*#3435* and *#792*).

30) There was an issue associated with groups and wells under RESV control for undersaturated systems, that has now been corrected, Thanks to *@tskille* for reporting the issue (*#4549*).

31) Fixed a couple of bugs associated with writing out the restart file using the *--enable-opm-rst-file=true* command line option, when running in parallel mode (*#4602* and *#4601*).

32) When running in parallel mode the region threshold pressures from all processes were not fully written out to the restart file, this has now been corrected (*#4503*).

33) Fixed a bug associated with the ROCK keyword in the PROPS section, not using the default PVTNUM region, when either ROCKOPTS keyword is absent from the deck, or when ROCKOPTS(ROCKOPT3) has been defaulted with 1* (*#3428*).

34) A minor bug with the SUMMARY utility program associated with opening the *.SMSPEC file has been fixed. The program will now print a warning when it fails to open the file, and will then continue processing the next summary file (*#3319*).

35) The well flux for injection perforations depends on the connected grid cell mobility in the cell, and not the upstream grid cell value. In thermal runs, this can lead to numerical problems if the mobility strongly depends on temperature, as reported in issue *#4244*. The solution was to remove the derivative for thermal flux for injector perforations in the Solver. Note that this fix will also affect isothermal cases as well; however, testing indicates that this only has a minor negative impact on convergence for non-isothermal runs (*#4262*, *#4281* and *#4282*).

Note, the commercial simulator requires that the well must be declared as an injector using the WECONINJE keyword before entering the fluid's injection temperature with the WTEMP keyword. OPM Flow's behavior is more robust, due to storing the temperature unconditionally for all wells (*#3218* and *#4265*). Thus, making the order of the WCONINJE and WTEMP keywords in the input deck irrelevant. Both keywords are in the SCHEDULE section..

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

36) For the Thermal Model, the simulator supports both the HEATCR and HEATCRT keywords in the GRID section; however, the implementation was incomplete, in that using HEATCR keyword would result in the simulation failing. This has now been addressed (*#3410*).

37) There was a problem with the adaptive time step algorithm, which uses the change of results between time steps, to estimate the next time step. In the case were there was no change in the solution between time steps, the algorithm may fail to calculate the next step, resulting in an assertion error and the simulator aborting. This has now been fixed (*#4415*).

38) Fix an error in the Todd-Longstaff model such that now the simulator only modifies the density, that is the effective gravity contribution, and not the volumes. The issue only effected the Solvent Model. The simulator now duplicates the results from test Case 2.1 in "A benchmark study on problems related to CO_2 storage in geologic formations" *https://link.springer.com/article/10.1007/s10596-009-9146-x*. See *#773* for details.

39) Fix an issue with the well modeling code for injection wells looking for an artificial lift quantity (ALQ), which has now been addressed (*#4461*).

40) Fixed an issue when comparing a well's calculated BHP against a well's BHP constraint, for both producers and injectors (*#4584*).

41) Under some circumstance production wells under a THP constraint may converge with the well injecting instead of producing, due to how the vertical flow performance table was evaluated (see issue *#4476*). This has now been addressed (*#4483*).

42) There was an error in the code that resulted in referencing the wrong indices for well connections, this has now been corrected (*#4304*).

43) If the command line parameter *–allow-distributed-wells* has been set or defaulted to false, indicating that distributed wells are not allowed. Then the simulator attempts to move all the all perforated cells for the wells to one process. Previously, the simulator would throw an exception if this was not successful; however, the exception was only thrown on one process causing OPM Flow to hang afterwards. This has now been fixed by throwing on all processes. In addition, the error message has been improved to indicate the reason for the simulator stopping (*#619*).

44) Fixed an issue associated with how distributed wells were allocated across the available processes (*#620*). Secondly, we only previously moved the perforated cells of one well to the new partition. In the case that a cell was also perforated by another well we might have moved only a few cells of that other well. The rest would remain where they were previously. Hence the well might still be distributed between multiple processors and the user would see the following exception:

```
Error: [opm/grid/common/ZoltanPartition.cpp:132] Well is distributed between
processes, which should not be the case!
```

To solve this problem we now make a full search in the well graph starting with a cell of the well to be moved. This will effectively move the cells of all wells whose cells are reachable via the well graph. As a result there should be no distributed wells across processes (*#621*).

45) There was a bug associated with when the WTEST keyword executed at the beginning of (the first time step of) a report step, if the well was also created at that report step. This led to an exception being thrown due to the simulator trying to reference the potentials array. This has now been fixed (*#4611* and *#4609*).

46) Fix bug in multi-segment well assembly where derivatives get overwritten whenever the segment flow direction is reversed, that is, when seg_upwind==outlet_segment_index (*#4538*).

47) There was an issue with writing out the segment connection pressures for multi-segment wells. Previously, the simulator incorrectly wrote the grid block pressures corrected to perforation depth, instead of the actual connection pressures. This has now been corrected (*#4468*).

48) For multi-segment wells, if there were declared connections not connected to the well's corresponding segments, then the simulator would crash. This has now been fixed for wells declared in the main input deck. However, for well specifications within ACTIONX and ACTIONW blocks, this may still be a problem, as like the commercial simulator, it is not possible to fully check all conditions within these blocks at the start of the run (*#4329*).

49) The simulator now checks for missing COMPSEGS keywords for declared multi-segment wells when reading the input deck, instead of during the simulation at the report step where the problem occurs. This is an improvement on *#4329*, that checked for the error during the simulation. The error message is now of the form:

```
unknown location(0): fatal error: in "MissingCOMPSEGS": Opm::OpmInputError:
Problem with keyword WELSEGS
In <memory string> line 38
Missing COMPSEGS keyword for the following multisegment well:
    PROD01 in <memory string> at line 38.
```

See *#3293* for details.

50) For multi-segment wells with Inflow Control Devices ("ICD"), if the liquid fraction flowing through a ICD segment was negligible, then this would introduce singular matrices problems in the Solver, resulting in numerical issues. This has now been resolved by placing a threshold on the liquid fraction,

such that it is not used in the connection viscosity calculations if it is below the threshold value (*#4274*).

51) There was a bug in the handling of multi-segment wells when the number of segments was altered during the run. The bug cause the simulator to throw an exception and to terminate. This has now been fixed (*#4239*).

52) Refactored the standard well bottom-hole calculation to ensure that the BHP limit is honored for standard wells. The multi-segment equivalent code was working correctly (*#4500*).

53) Corrected a regression associated with getting the THP limit for producers in the Network Model (*#4289*).

54) Fixed a bug associated with a well's voidage injection rate calculation that did not take into account a well's water injection voidage rate (*#3346*).

55) In the SCHEDULE section, if the current value of WCONPROD(THP) is acting as a constraint instead of a target, and has been defaulted, then WCONPROD(THP) was skipped when checking for constraints in the Network Model. This has now been corrected (*#4407*).

56) For wells that have been STOPPED, the well mode of control indicator (WMCTL) should be set to zero, same as for SHUT well. Previously, this was not the case, but has now be corrected (*#3438*).

B.1.5 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:

```
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
```

Commenting out the keyword will enable the case to run. See issue *#3200* for details.

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) 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).

14) 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).

15) 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).

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

17) 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).

18) 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).

19) 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).

20) 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).

21) **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 *Irijkels* for reporting the issue. See *#4597* for details.**

22) **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.**

Jostein Alvestad, Kai Bao, David Baxendale, Markus Blatt, Joshua Charles Bowden, Paul Egberts, **Arne Morten Kvarving (Release Manager)**, David Landa-Marbán, Cintia Goncalves Machado, Halvor Møll Nilsen, Håkon Hægland, Ove Sævareid, Atgeirr Flø Rasmussen, Alf Birger Rustad, Tor Harald Sandve, Bård Skaflestad, Torbjørn Skille, and Pieter J. Verveer.

B.2 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 LETI[345] family of relative permeability and capillary pressure functions that can be used as a replacement for Corey[346] 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 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.

B.2.1 New and Deprecated Command Line Options

The major command line changes made for this release are summarized in Table B.3

No.	Variable Name	Description	Default
OPM Flow 2022-10 New And Deprecated Command Line Options			
I	--linear-solver	A defined quoted character string that sets the configuration of the solver, valid values are: 1) ilu0 (default), 2) cpr (an alias for cpr_trueimpes)[347] [348] and [349] 3) cpr_quasiimpes, 4) cpr_trueimpes, 5) cprw, 6) amg,[350] 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"

---

[345] *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.*

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

[347] *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).*

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

[349] *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.*

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

No.	Variable Name	Description	Default
		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'. 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. See #4125.	
2	--linsolver	Renamed to --linear-solver See #4125.	"ilu0"
3	--linear-solver-verbosity	A positive integer value that defines the output from linear solver: 0 : No extra output, 1 : output per solution iteration, or 2 : output per iteration. See #4130.	0
4	--flow-linear-solver-verbosity	Renamed to --linear-solver-verbosity. See #4130.	0
5	--linear-solver-require-full-sparsity-pattern	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. Removed, see #4243 and #4255.	false
6	--min-strict-cnv-iter	A positive integer that sets the minimum number of Newton iterations before relaxed tolerances are used for the CNV convergence criterion. See #4086.	0
7	--max-strict-iter	Renamed to --min-strict-cnv-iter See #4086.	0
8	--newton-max-iterations	A positive integer that defines the maximum number of Newton iterations per time step used by the simulator. See #4234, #4185, #4223, #741 and #749.	20
9	--flow-newton-max-iterations	Renamed to --newton-max-iterations. See #4234, #4185, #4223 and #741.	
10	--newton-min-iterations	A real positive integer that sets the minimum number of Newton iterations per time step used by the simulator. See #4141.	1

Table title: **OPM Flow 2022-10 New And Deprecated Command Line Options**

**OPM Flow 2022-10 New And Deprecated Command Line Options**
No.	**Variable Name**	**Description**	**Default**
11	--flow-newton-min-iterations	Renamed to --newton-min-iterations See #4141.	
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[351] 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

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.

---

[351] *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.*

OPM Flow 2022-10 New And Deprecated Command Line Options			
No.	**Variable Name**	**Description**	**Default**
3)	Cells colored in red in the "No." column indicate a deprecated command line option for this release.		

Table B.3: OPM Flow 2022-10 New and Deprecated Command Line Options

B.2.2 NEW FEATURES

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 implement 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, for incorporating the Joule-Thomson effect in models (*#3029*), as well as incorporating Joule-Thomson effect in energy calculations (*#500*). See keywords GASJT, OILJT 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.

Although the Polymer Molecular Weight Transport model has been tested using metric units, using either field or laboratory units with the option should be considered experimental.

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 precipitation.

15) Added water evaporation and salt precipitation for three-phase runs (oil, water and gas). Previously the simulator only supported gas-water models. Note that currently the simulator does <u>not</u> support:

   • Water evaporation with multi-segment wells, only standard wells are supported.

   • Brine with multi-segment wells, only standard wells are supported.

   See *#3869* for details.

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 WVFPEXP keyword in the SCHEDULE section with the WVFPEXP(IMPEXP) and WVFPEXP(CONTROL) options (*#4100* and *#3837*).

B.2.3 IMPROVEMENTS

Improvements include:

1) 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.

2) 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*).

3) 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*).

4) Adapt drift compensation code to account for isolated cells and various other improvements (*#3968* and *#699*).

5) Re-factored the analytical and numerical aquifer code to have a common base, and implemented the code in the black-oil aquifer model (*#3994*).

6) Previously, if there were any invalid aquifer connections, the simulator world 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*).

7) 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 [352] 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 extend to a maximum dimensionless time value of 10,000, which should enable better consistency with the commercial simulator (*#3099*).

8) 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*).

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

9) 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*).

10) 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*.

11) Previously, the *.DBG file contained hundreds of *computeBhpAtThpLimitProd()* messages per well, which made examining the output difficulty, these messages have now been switched off, but are still available to developers via a compile switch (*#4097*).

12) 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*).

13) 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* for details.

14) 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.

15) 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.

16) 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*).

17) 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*).

18) 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*).

19) Improved numerical performance by applying heuristic scaling of trueimpes weights for the cpr and cprw methods (*#4194* and *#4230*).

20) 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.

21) 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.

22) 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*).

23) 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*.

24) 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*).

25) 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*).

26) 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*.

27) 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 initial 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*).

28) Improved the convergence of newly opened wells (*#4149*). Secondly, only apply drift compensation when wells are active (*#4102*).

29) 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*).

30) 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*).

31) Improved the standard well code by applying a "Regularization Factor" to avoid problematic wells prematurely shutting-in (*#3957*).

32) 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*).

33) Improved well tolerance criteria by relaxing the tolerance after six Newton iterations so that unsolvable wells remain open (*#3859*).

34) Various improvements to OPMRUN, including corrections and additions to the keyword templates, together with the Production Schedule Utility being extended to generate production schedules based on monthly rate and monthly volume input data (*#73* and *#72*).

In addition, the following new SUMMARY keywords are now recognized as described by the comments in Table B.4.

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, BWIP, 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*.

No.	Summary Keyword	Comment
3	GEFF, WEFF, and WEFFG	Added support for the GEFF, WEFF, and WEFFG summary vectors that report the efficiency factors at the well (WEFAC) and group (GEFAC) levels. WEFFG additionally accounts for efficiency factors in a well's superior groups in the group tree (*#3060*).
4	Well Connection Vectors	Improved support for writing out well connection vectors, to the SUMMARY file (*#3094* and *#3091*).

Table B.4: New SUMMARY Keywords for the 2022-10 Release

B.2.4 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 turtuosity 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 STOIIP) 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 1*, 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 a bug in the Salt Precipitation Model in how the solid salt accumulation term was calculated. This has now been corrected (*#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 TpfaLinearizer for when the MULTFLT keyword is used in the SCHEDULE section (*#750*, *#4232*, *#4207* and *#748*).

38) A bug with the TpfaLinearizer 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 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 computeWellConnectionDensitesPressures 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*).

B.2.5 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:

```
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.
```

Commenting out the keyword will enable the case to run. See issue *#3200* for details.

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*).

B.3 RELEASE 2022-04

The 2022-04 release consists of some new features and various improvements and bug fixes. Highlights for this release include: implementation of the Salt Precipitation Model, several ACTIONX implementation improvements – including support for the COMPSEGS, WELSEGS and WSGVALV keywords in an ACTIONX block, improvements to the CO2STORE model to work with numerical aquifers and to account for thermal effects, support for gas lift optimization for multi-lateral wells, the addition of various SUMMARY vectors, 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 (2.8) has been added.

B.3.1 NEW AND DEPRECATED COMMAND LINE OPTIONS

The major command line changes made for this release are summarized in Table B.5

No.	Variable Name	Description	Default
OPM Flow 2022-04 New And Deprecated Command Line Options			
1	--sched-restart	A Boolean value that determines for a restart run if the case should initialize wells and groups from the historical SCHEDULE section (true), or from the well and group data on the restart file (false). Note that the commercial simulator always uses data from the restart file (false).	false
2	--enable-tracer-model	A Boolean value set to true or false that turns on (true) or off (false) transport tracer calculations for when tracers have been declared in the input deck. This option is deprecated (#3717).	

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

Table B.5: OPM Flow 2022-04 New and Deprecated Command Line Options

B.3.2 NEW FEATURES

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

1) The Python version of the opm-parser is used in a number of scripts by some users for parsing specific parts of a data deck. The efficiency of the scripts are improved as the Python version is now aware which section a keyword belongs to and can ignore sections when getting the requested keyword(s). This feature was added in the 2021-10 release but was not documented for that release (#2527).

2) ACTIONX implementation improvements include:

   a) Support for the MULTX, MULTX-, MULTY, MULTY-, MULTZ and MULTZ- keywords in an ACTIONX block (#3686).

   b) Implemented support to access grid property data to enable the COMPDAT, COMPLUMP, etc., type of keywords to work within an ACTIONX bloc (#2828).

  c) Added support for the COMPSEGS, WELSEGS and WSGVALV keywords within an ACTIONX block (*#2849*, *#2852*, and *#2885*).

  d) Added support for the WELTARG keyword within an ACTIONX block (*#2892*).

  e) Added support for the WTMULT keyword within an ACTIONX block (*#2906*).

  f) Added a missing ACTIONX comparison (*#2898*).

  g) Implemented support for the NEXTSTEP keyword in the SCHEDULE section (*#3614*, *#3721* and *#3736*) as well as support in an ACTIONX block (*#2904*).

  h) Added the NEXT keyword in the SCHEDULE section as an alias for NEXTSTEP (*#2902*) as well as support for NEXT in an ACTIONX block (*#2905*).

3) Added support for the CO2STORE model to use numerical aquifers (*#3711*).

4) Enabled the CO2STORE model to account for thermal effects (*#3724*).

5) Added support for the GRAVITY keyword in the PROPS section (*#3670*).

6) RESTART file improvements:

  a) Added support for the Extended Network Model (*#2857*, *#2825*, *#2809*, *#2808*, *#2779* and *#2804*).

  b) Added support for reading and writing TRACER data to the RESTART file (*#2869*, *#2861*, *#2864*, *#2859*, *#2855*, *#3702*, *#2854*, *#2879*, *#3708* and *#3718*).

  c) Added additional entries for well connections (*#2427*) and improved error reporting when loading RESTART files (*#2759*).

  d) Load and save GCONINJE guide rate injection settings for group water injection to and from the RESTART file (*#2888*).

  e) Read and write GLIFTOPT options to the RESTART file (*#2794* and *#2777*), load and store WLIFTOPT options if enabled for a well (*#2791* and *#2770*).

  f) Load and save group efficiency factor values to and from the RESTART file (*#2773*).

  g) Added support for storing and loading group constraints at the field level set by the GCONPROD and GCONINJE keywords (*#2814*).

7) Added support for the WTMULT keyword in the SCHEDULE section (*#2763*).

8) Implemented the Salt Precipitation Model. This is an extension of the brine module to deal with salt precipitation/dissolution and allowing primary variable switching between salt concentration and solid(precipitated) see *#3729*, *#3759*, *#681* and *#490*. In addition the following keywords have been added and/or updated:

  a) The SALTSOL keyword in the PROPS section now supports setting the salt solubility by region (*#2593*). Note this is an OPM Flow specific keyword used with the simulator's Salt Precipitation model.

  b) Added the SALTPVD keyword as part of OPM Flow's Salt Precipitation Model that defines the initial precipitated salt volume fraction versus depth tables for each equilibration region (*#2920*).

  c) Implemented PRECSALT keyword in the RUNSPEC section that activates OPM Flow's Salt Precipitation Model (*#2595*).

  d) Fixed a unit error with the units for salt concentration on the SALTVD keyword changing the units for the SALTCON parameter from lb/ft^3 to the correct units of lb/stb (*#2930*).

  e) Added the SALT keyword to define the initial equilibration salt concentration for all grid blocks and the SALTP keyword to define initial equilibration precipitated salt volume fraction (*#2931* and *#3774*).

f) Added the RVW keyword in the SOLUTION section that defines the initial equilibration vaporized water in gas ratio for all grid blocks for use with the Vaporized Water Model (*#2968*, *#3830*, *#684* and *#491*).

9) Added support for gas lift optimization for multi-segment wells (*#3812*).

10) Added support for gas-water initialization for two-phase runs using PVDG and PVTW keywords in the PROPS section. Two-phase gas-water models will now run; however, the RVCONST and the RVCONSTT keywords are currently unsupported and thus the liquid yields have to be calculated manually (*#3838*).

11) Added support for the WVFPEXP keyword in the SCHEDULE section (*#2988* and *#3866*).

12) Added support for LIFTOPT(TSTEP) option that defines the frequency of the gas lift optimization calculations. This was previously documented as implemented but was not. The functionality has now been implemented in this release (*#3777*).

13) Previously, the water only and water only with thermal models were standalone binaries. With this release these models are now incorporated into the main OPM Flow binary (*#3892* and *#3891*).

14) The VAPWAT keyword in the RUNSPEC section, that activates the vaporized water phase, is now active for this release for gas-water systems only. Work on the three phase case is currently under way and is expected to be implemented in the next release (*#2989* and *#2591*).

In addition, the following new SUMMARY keywords are now recognized as described by the comments in Table B.6.

No.	Summary Keyword	Comment
1	BGPR and BWPR	Added support for block-level gas (BGPR) and water (BWPR) phase pressures(*#3827* and *#2967*).
2	BNSAT	Implemented block level solvent saturation summary output keyword BNSAT (*#3861* and *#2986*).
3	BTCNFHEA	Added support for the block temperature vector (*#2962* and *#3820*).
4	FSIR, FSIT FSPR, FSPT, FSPC, and FSIP	Added support for salt production rates for the OPM Flow's Salt Precipitation model.
5	GSIR, GSIT, GSPR, and GSPC	Added support for salt production rates for the OPM Flow's Salt Precipitation model. Not GSPT is currently not supported.
6	GWIGR	Previously the simulator would tie reporting of group level Guide Rates to whether or not a group had any guide rates for production; however, this is insufficient for group level injection guide rates. OPM Flow has now been updated to handle group level water injection guide rate reporting on the SUMMARY file via the GWIGR variable (*#3612* and *#3598*).
7	MSUMBUG MSUMCOMM MSUMERR MSUMMESS MSUMPROB MSUMWARN	In the 2021-04 release the message keywords were recognized by the parser; however, no data associated with these vectors is written to file (*#2234*). This is still the case.

No.	Summary Keyword	Comment
8	ELAPSED MLINEARS MSUMLINS MSUMNEWT NEWTON NLINEARS NLINSMAX NLINSMIN, STEPTYPE TCPU TCPUDAY TCPUTS TELAPLIN TIMESTEP	Various performance vectors are now supported either declared individually or via the PERFORMA keyword in the SUMMARY section. The ELASPSED, STEPTYPE, TCPUDAY, TCPUTS and TELAPLIN vectors are written out but all values are set to zero. See #2953 and #3801.
9	R*FR and R*FT	Added support for the following inter-region flow summary vectors: RGFR, RGFR+, RGFR-, RGFT, RGFT+, RGFT, RGFTG, RGFTL, ROFR, ROFR+, ROFR-, ROFT, ROFT+, ROFT, ROFTG, ROFTL, RWFR, RWFR+, RWFR-, RWFT, RWFT+, and RWFT- Note that variables ending in a + or − are OPM Flow's implementation of the commercial compositional simulator's variables (#3811, #3796, #2958, #2945, #2955, #2929, and #2928).
10	WSIR, WSIT WSPR, WSPT, and WSPC	Added support for salt production rates for the OPM Flow's Salt Precipitation model.
11	WSTAT	Added support for the well status summary variable (#2853).
12	WWIRT	In the 2021-04 release support for the WWIRT vector for writing out the water injection rate target was implemented (#2071); however, the field (FWIRT) and Group (GWIRT) vectors were not implemented. A warning message is printed stating the fact.

Table B.6: New SUMMARY Keywords for the 2022-04 Release

B.3.3 IMPROVEMENTS

Improvements include:

1) Improve ESmry file output by not writing out empty elements (#2915).

2) Improved how the summary keywords are handled for inter-region summary vectors in ESMRY file, to give a consistent naming convention (#2960).

3) If the simulator fails to find the a cell's saturation pressure (bubble and dew point pressure) then the following message was printed:

```
Finding the dew point pressure failed for 2 cells [1467066, 1467066]
Finding the dew point pressure failed for 8 cells [1467063, 1467063, 1467066,
1467066, 1467066, 1467066, 1467066, 1467066]
```

This has now be changed to be more readable to:

```
Finding the dew point pressure failed for 1 cell [(71,89,46)]
Finding the dew point pressure failed for 2 cells [(68,89,46), (71,89,46)]
```

See *#3828*.

4) Improvements on how the well potentials are calculated when the wells are under guide rate control (*#3719*).

5) Improvements on how the well rates are calculated for when the wells are or not under group control control (#3645).

B.3.4 BUG FIXES

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

1) In models with numerical aquifers, the numerical aquifer cells have large pore volumes which unduly influence the convergence criteria, indicating convergence has been achieved when in fact convergence has not been reached. This has now been corrected (*#3638*).

2) For numerical aquifers, the cell permeability used to compute aquifer to reservoir transmissibilities, did not take into account the MULTX, MULTY and MULTZ values applied to the reservoir cell; these are now taken into account when calculating the aquifer to reservoir transmissibilities (*#2919*).

3) ACTIONX bug fixes include:

   a) Fixed a bug associated with the ACTIONX keyword when a well is fully defined in an ACTIONX block and then referenced afterwards in the main deck (*#2895*).

   b) Fixed a bug associated with the ACTIONX keyword when a standard well is fully defined in the main deck and then converted to a multi-segment well in an ACTIONX block (*#2895*).

4) Corrected a bug in the C02STORE model associated with the reference oil density (*#3727*).

5) Gas lift and gas lift optimization issues corrected include:

   a) Fixed an incorrect gas lift rate calculation based on IGLR and ALQ (*#2807*).

   b) Corrected an issue with applying gas, oil and water reduction calculation in the gas lift optimization calculation procedure (*#3678* and *#3673*).

   c) Fixed an issue when both well and group controls restrict gas lift availability (*#3728*).

   d) Previously, not all groups were considered when reducing oil rates to satisfy oil group limits. This has now been corrected (*#3747*).

   e) Defaulting GLIFOPTT(MAXLIFT) or GLIFTOPT(MXGAS) would cause the simulator to throw an error, this has now been rectified (*#2884*).

   f) The VFPPROD(ALQ) default value of 1* is " " or undefined, that covers the case when the ALQ variable is not entered, except for when gas lift is employed in the model. When gas lift is active then the default value for ALQ is set to GRAT. Secondly, it is possible to have only the OIL and WATER keywords in the RUNSPEC section and to use gas lift for the wells, without declaring the GAS phase in the RUNSPEC section. If the ALQ and VFPPROD(ALQ-DATA) parameters are absent then the VFPPROD(GFR-DATA) data will be used based on the flowing GOR plus the stipulated gas lift gas. This logic was previously missing from the simulator but is now implemented (*#2971*, *#3833* and *#3706*).

   g) Ensure that group/well guide rates (i.e. the distribution between wells/groups) are updated when gas lift volumes vary during iterations, as defined by LIFTOPT(OPTLIFT) set to YES. This will also reduce the number of oscillations during the Newton iterations (*#3807*).

   h) If a well is under a group that is limited by a target, it should use as little gas lift gas as possible. The reduction algorithm will now reduce the gas lift of the well as long as the groups potential is above the groups target (*#3795*).

    i)   Fixed a bug associated with a group's gas lift artificial lift gas rate plus actual gas production being greater than the group's maximum gas rate as declared via the MXGAS parameter on the GLIFTOPT keyword (*#3797*).

6)   Using the GRAVITY keyword in the PROPS section caused an exception to be raised and the simulator to abort. This has been fixed by implementing the GRAVITY keyword (*#3670*).

7)   Fixed a bug associated with the default values on the NETBALAN keyword in the SCHEDULE section.

8)   Added support for PVT extrapolation in the extended black-oil model. Previously, if the required values were outside the values supplied by the input keywords, then the simulator raised an exception and would abort (*#680*).

9)   RESTART file bug fixes:

    a)   Fixed an issue with the field, group, and well level cumulative production curves of solution/free oil and gas not being continuous in a restarted simulation run (*#2871*).

    b)   If a well's BHP reference depth is defaulted and there are no connections for the well then the default missing value of -1.0E=20 should be written to the RESTART file, previously this was not the case (*#2908*). This also resolves issue *#2442*.

    c)   Fixed a bug related to writing out tracer data to the restart file (*#2878*).

    d)   For a restart run, previously the RPTRST keyword in the SOLUTION section was not retained for the run. This has now been rectified (*#2876*).

    e)   The OPM Flow specific PORV_RC and TMULT_RC solution arrays were incorrectly marked as commercial simulator compatible arrays, this would cause errors when loading the RESTART file using the commercial simulator. This has now been fixed (*#3683*).

    f)   Previously, the cumulative oil and water volumes were set to zero when restarting a simulation. This has now been rectified by using the correct volumes (*#2805*).

    g)   Fixed an issue with loading LIFTOPT from the RESTART file (*#2790*).

    h)   For the restart group, well and connection data the XWEL keyword items 36 to 39 need to be defined (see Table F.24). The current understanding is that the values are same as items one through three on the same keyword. Secondly, exponent letters need to uppercase (1.26E-04) and not lowercase (1.26e-04). Both issues have been address in *#2975*.

10)   Previously, the RPTSCHED Well Production and Injection reports printed zeros for the field rates and totals, this has now been rectified (*#2584* and *#2880*).

11)   In parallel runs, applying transmissibility multipliers in the SCHEDULE section would cause an exception to be raised and the simulator to abort. This has now been fixed (*#2923*).

12)   SUMMARY output bug fixes:

    a)   Fixed an issue with the surface gas production volumes having incorrect field units for free and associated (dissolved) gas. This error was specific to runs using field units as opposed to metric units (*#2918*).

    b)   Fixed a bug in parallel runs which caused the SUMMARY vectors associated with the free gas, dissolved gas, and the oil and vaporized oil vectors for all objects (field, well, etc.) to be incorrect due to the dissolved phase being under reported. This also effected the free phase volumes as well as Free (Oil, Gas) is calculated from Total (Oil, Gas) - Dissolved (Oil, Gas). Now both sequential and parallel runs give the same results (*#3765*).

13)   Incorporated well efficiency, via the WEFAC keyword in the SCHEDULE section, in network calculations. Note that only the default value for WEFAC(WELNETWK) of YES is supported for the Extended Network Model (*#3730*).

14) Fixed WELTARG not supporting the LIFT option (*#2881*).

15) Corrected an issue with how wells are handled for the WECON keyword (*#3720*).

16) If the WRFT keyword was used to report RFT data to the WRFT file and the well had no connections then OPM Flow would write the records to the file. This would cause an issue with OPM ResInsight and other post-processing software attempting to read the resulting WRFT file. OPM Flow no longer writes the records if there are no connections to the well (*#2909*).

17) Using the WTEST keyword to test physically or economically shut-in wells, OPM Flow previously did not check if a well had been manually shut-in via the input deck. This has been corrected such that wells manually shut-in will now not longer be tested (*#3713*).

18) Fixed a bug associated wells prematurely closing due to negative flow potentials *(#3834*).

19) When converting from surface to reservoir rates the simulator needs to solve a 2x2 system of equations using Cramer's Rule, that is d = 1-rs*rv, where d is the determinant. If d is zero the system is singular and the system unsolvable. This should not happen with physical values of rs and rv, but for unconverged solutions this may happen due to extrapolation of rs/rv tables to unphysical pressures. The fix removes a hard throw and instead ignores the dissolved/vaporized part and tries to continue. Some times this is sufficient to get a more reasonable solution in the next Newton iteration, other times not, and the simulator needs to chop the time step, etc. (*#3853* and *#3855*).

20) For the WELSPECS keyword the GRPNAME parameter should not be set to FIELD; however, this was not trapped and resulted in a program exception. This has been rectified by issuing an error message for when GRPNAME is set to FIELD (*#2974*).

21) When multi-segment wells were initially opened the oil and water rates were zero after being scaled because the perforation rates entering calculateSegmentRates routine only had a value for the gas rate and zero for the water and oil rates. This has now been corrected by ensuring the top segment rates will be approximately the same with the well rates after scaling from zero rates from opening the well (*#3839*).

22) Previously wells would per-maturely close due to the economic limits set via the WECON keyword because of inaccurate well potentials and inaccurate ratios (WOR, GOR, etc) caused by negative rates. This has now been corrected (*#3851*).

23) When multi-segment wells are initially opened the well rates and well potentials are zero causing a numerical issue due to creating a singular matrix. This fix ensures we have sensible initial rates etc. for the wells (*#3847*).

24) For multi-segment wells changed from multiplicative to addition when updating the pressure for each segment when the bottom-hole pressure is changed. This is a more robust treatment (*#3835*).

25) If there are no analytical aquifer connections, for example, if the AQUANCON keyword has not been entered or that all the defined connections are invalid, then the simulator would stop. This is still the case but now a more descriptive error message is printed (*#2973*).

26) If there are no cells with valid corner-point geometry, typically caused by using GDFILE to read non-finite data such as all ZCORN = -1.0E+20, then the simulator will throw an exception. Now instead an error message is issued and the simulator terminates gracefully (*#3845* and *#2979*).

27) Fixed an issue with being unable to calculate a well's BHP from its THP limit (*#3760*).

28) Under some circumstances a well's BHP constraint may be violated during an iteration cycle, for example, when an injector is opened to give pressure support to the producers it may take a few Newton iterations for the pressure support to be propagated and the solution to converge. Before convergence is achieved the simulator may calculate negative potentials resulting in the well being shut-in. This has now been rectified (*#3834*).

29) Check if group and well guide rates have been violated and also ensure that a group's efficiency is accounted for when summing guide rates (*#3814*).

30) When a restarted model uses SKIPREST, there must be either a DATES or TSTEP keywords that correspond exactly to the requested restart time. The previous diagnostic message for:

missing record in DATES

```
Error: Problem with keyword DATES
In CASE.DATA line 223
At date: 2019-04-18 - scanned past restart data: 2019-04-12
```

and missing report step in TSTEP

```
Error: Problem with keyword TSTEP
In PRED_FLOW.DATA line 219
At date: 2019-04-16 - scanned past restart data: 2019-04-12
```

did not offer sufficient information to the user as to what the underlying issue might be. The new message are now for missing record in DATES:

```
Error: Problem with keyword DATES
In CASE.DATA line 223
In a restarted simulation using SKIPREST, the DATES keyword must have
a record corresponding to the RESTART time 12-Apr-2019 00:00:00.
Reached time 18-Apr-2019 00:00:00 without an intervening record.
```

and missing report step in TSTEP:

```
Error: Problem with keyword TSTEP
In CASE.DATA line 219
In a restarted simulation using SKIPREST, the TSTEP keyword must have
a report step corresponding to the RESTART time 12-Apr-2019 00:00:00.
Reached time 16-Apr-2019 00:00:00 without an intervening report step.
```

31) If a well has been declared as SHUT via the WCONINJE or WCONPROD keywords but is later activated using the WELOPEN, keyword we must record this status change in the well's internal has_produced or has_injected flags as appropriate. Otherwise, the counts of "abandoned" wells (summary vectors [FG]MW[IP]A) will not be correct (#2961).

32) If a well under group control is constrained such that the well's THP is below the well's THP limit, then avoid switching to THP control if this results in production or injection rates increasing. For example, if the well's group has a zero rate then we do not want to switch the well control to THP control as this will increase the well's production or injection rate (#3824).

33) If an injection well had an insignificant injection rate then the commercial simulator returns zero for the THP regardless of the BHP. OPM Flow now does the same (#3773).

34) Fixed an issue with group and well guide rates not being updated after new wells are opened up (#3771).

35) In some rare circumstances the WOR/WCT/GOR/GLR limits may be exceeded at the well level but not at any of the individual connections. This can occur due to numerical noise caused by very small rates. If this occurs the simulator will now not shut the well (#3758).

36) Previously, the WTEST code only checked the BHP constraints and potentially opened wells limited by a THP constraint. This has now been addressed by checking for both BHP and THP constraints before opening wells using the WTEST facility. (#3803 and #3816).

37) If the well residuals contained NaNs (Not a Number) this was counted as an error, now the event is more correctly recorded as unconverged. The simulator behavior remains unchanged (#3867).

38) Fix a bug associated with the command line -shut-unsolvable-wells equals true option. The bug did not effect the default behavior (#3863).

39) Fixed an error associated with the saturated density in the DRSDTCON keyword (*#3884* and *#3878*).

40) Added the DR, DTHETA and OUTRAD keywords as unsupported keywords with messages to enable the user to debug the input deck (*#3875* and *#3883*).

41) Fixed an issue with checking well potentials, now OPM Flow only checks if wells have negative potentials if the command line enable-well-operabilty-check=true, which is the default behavior (*#3874* and *#3885*).

42) Fixed an issue with initialization when there is no dissolved gas in the model (*#3871* and *#3877*).

43) Stopped wells are wells that are shut-in at the surface and are operable in order to allow cross-flow in the wellbore, as opposed to wells that are shut-in at the sand face. Now stopped wells are changed to shut -in if they cannot converge after repeated time-step chopping. The change makes the well modeling code more robust (*#3890* and *#3872*).

44) Fixed an error associated with Brine model accessing an uninitialized variable if the enableSaltPrecipitation Boolean variable is set to false, that is salt precipitation is not enabled (*#691* and *#690*).

45) Fixed an issue with the COMPLUMP keyword with the indices I, J, K1 and K2 not having the default value of zero (*#3006* and *#3011*).

B.3.5 KNOWN ISSUES

1) 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.

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.

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) When using the AQUANCON keyword to declare declare analytical aquifer connections, using for example:

```
--
--                    ANALYTIC AQUIFER CONNECTION
--
--        ID      ---------- BOX ---------   CONNECT  AQF    AQF    ADJOIN
--        NUMBER I1   I2    J1   J2   K1  K2  FACE     INFLX  MULTI  CELLS
AQUANCON
          1      3    54   117  142   1   30  J+       1*     1*     1*   /
          2     83   131    20   48   1   30  J-       1*     1*     1*   /
          2     53    84     2   19   1   30  J-       1*     1*     1*   /
/
```

Then if there are invalid aquifer connections OPM Flow will issue a warning message for each invalid connection. If there are numerous invalid connections because of the irregular shape of the reservoir edges then the simulator will take a long time time to write out all the invalid connections. The work around is to more precisely define the aquifer connection data (*#2993*).

9) 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*).

10) 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*).

11) 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*).

12) 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*).

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

14) 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 work flow in declaring wells (*#2891* and *#2895*).

15) 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*).

16) 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*).

17) 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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B.4 RELEASE 2021-10

The 2021-10 release consists of some new features and various improvements and bug fixes. Highlights for this release includes support for a new output SUMMARY file type Enhanced SMRY (*.ESMRY), passive tracer support, two phase gas-water support and single phase water support (only for Enumeration Initialization), Carter-Tracy and numerical aquifers support with the CO_2 Storage Model, and the implementation of the Microbially Induced Calcite Precipitation ("MICP") model used to investigate CO_2 leakage remediation.

B.4.1 NEW AND DEPRECATED COMMAND LINE OPTIONS

The major command line changes made for this release are summarized in Table B.7

**OPM Flow 2021-10 New And Deprecated Command Line Options**
No.	**Variable Name**	**Description**	**Default**
1	--accelerator-mode	A defined character string that defines the usage of the GPU (cusparseSolver or openclSolver) or FPGA (fpgaSolver) as the linear solver, usage '--accelerator-mode=[none|cusparse|opencl|fpga|amgcl]'.	"none"
2	--enable-esmry	A Boolean value that switches on (true) or off (false) the output SUMMARY vectors to the ESMRY file for fast loading of summary data (*#2590*, *#2606*, *#2609*, *#2621*, and *#3453*).	false
3	--enable-well-operability-check-iter	A Boolean value set to true or false that enables (true) checking of a well's operating status <u>during iterations</u>, or disables (false) the checking <u>during iterations.</u>	false
4	--force-disable-resv-fluid-in-place-output	A Boolean value set to true or false that instructs OPM Flow to <u>not to print</u> the Reservoir Volume Fluid In-Place report after each report time step (true) or not (false).	false
5	--fpga-bitstream	A character string that specifies the bit stream file for the fpgaSolver (including path), usage: '--fpga-bitstream=<filename>'.	""
6	--linsolver	Command line parameter changed from --linear-solver to --lin-solver Functionality is the same as before.	"ilu0"
7	--max-newton-iterations-with-inner-well-iterations	A positive integer that specifies the maximum newton iterations with inner well iterations.	8.0
8	--max-temperature-change	A real positive value that stipulates the maximum absolute change of temperature in a single iteration.	5

No.	Variable Name	Description	Default
	OPM Flow 2021-10 New And Deprecated Command Line Options		
9	--maximum-number-of-well-switches	A positive integer values that stipulates the maximum number of times a well can switch to the same control.	3
10	--relaxed-pressure-tol-msw	A real positive value that sets the relaxation tolerance for the multi-segment well <u>pressure</u> solution.	50000
11	--relaxed-well-flow-tol	A real positive value that sets the relaxation tolerance for the well flow residual.	1.0
	-sched-restart	A Boolean value that determines for a restart run if the case should initialize wells and groups from the historical SCHEDULE section (true), or from the well and group data on the restart file (false). Note that the commercial simulator always uses data from the restart file (false). (*#3601*). <u>This option was also in the previous release.</u>	true
12	--shut-unsolvable-wells	A Boolean value that determines if the simulator should shut unsolvable wells (true), or not (false).	false
13	--solver-continue-on-convergence-failure	A Boolean value that stipulates if the simulator should continue (true) instead of stopping (false) when the minimum solver time step is reached.	false
14	--strict-inner-iter-wells	A positive integer that specifies the number of inner well iterations with strict tolerance.	40
15	--strict-outer-iter-wells	A positive integer that specifies the number of newton iterations for which wells are checked with strict tolerance.	99
16	--temperature-max	A real positive value that sets the maximum absolute temperature.	400
17	--temperature-min	A real positive value that sets the minimum absolute temperature.	280
18	--gpu-mode	Use GPU cusparseSolver or openclSolver as the linear solver, usage: '--gpu-mode=[none|cusparse|opencl]'	
19	--relaxed-flow-tol-inner-iter-msw	Relaxed tolerance for the inner iteration for the MSW flow solution.	
20	--relaxed-pressure-tol-inner-iter-msw	Relaxed tolerance for the inner iteration for the MSW pressure solution.	
21	--strict-inner-iter-ms-wells	Number of inner iterations for multi-segment wells with strict tolerance.	

OPM Flow 2021-10 New And Deprecated Command Line Options			
No.	**Variable Name**	**Description**	**Default**
22	--use-inner-iterations-ms-wells	Use nested iterations for multi-segment wells.	
23	--use-inner-iterations-wells	Use nested iterations for standard wells.	

Notes:

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

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

Table B.7: OPM Flow 2021-10 New and Deprecated Command Line Options

B.4.2 NEW FEATURES

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

1) Added a new output SUMMARY file type Enhanced SMRY (*.ESMRY) that is optimized for fast loading of selected vectors by post-processing applications. The *.ESMRY file is re-written for every time step and does not have a performance impact on the simulation. The file type is compatible with OPM ResInsight and the option is activated via the enable-esmry=true command line option (*#2590*, *#2606*, *#2609*, *#2621*, and *#3453*).

2) Passive tracer support has now been implemented in this release via the TRACER, TRACERS and TVDP keywords. The feature is activated by the command line variable -enable-tracer-mode and is by default set to "true". Testing indicates the results are comparable to the commercial simulator. Tracer saturations can be visualized in OPM ResInsight together with the field and well SUMMARY vectors. Work on partitioning tracer support, tracers that transfer between phases, for example a gas phase tracer dissolving into the oil phase, is ongoing (*#2553* and *#3433*).

3) Added two phase gas-water support and single phase water support. Note this only works with Enumeration Initialization, that is the standard Equilibrium Initialization will result in OPM Flow throwing an exception since currently Equilibrium Initialization only works when oil is present in the model (*#3454*).

4) Carter-Tracy aquifers (AQUCT keyword in the GRID section) can now be used with the CO_2 Storage Model (CO2STORE keyword in the RUNSPEC section). In addition, the TEMP parameter on the AQUCT keyword may be used to define the initial temperature of the aquifer at the aquifer's datum depth (*#2694*).

5) Numerical aquifers (AQUNUM keyword in the GRID section) can also now be used with the CO_2 Storage Model, CO2STORE keyword in the RUNSPEC section (*#3532*).

6) Implemented the Microbially Induced Calcite Precipitation ("MICP") model used to investigate CO_2 leakage remediation. The module requires the WATER and MICP keywords in the RUNSPEC section, in addition to the MICPPARA keyword in the PROPS section to define the model parameters. Enumeration Initialization is via the SBIOF, SCALC, SMICR, SOXYG, and SUREA keywords in the SOLUTION section, to set the initial values for all cells in the model. The WMICP keyword in the SCHEDULE section sets the injection concentrations for the wells (*#2743*, *#671*, *#3617*, and *#3590*).

7) Added the calculation of the SUMMARY variable FPR for when there is no oil in the system (*#3491*).

8) COMPORD added the DEPTH ordering option to the keyword, all options on the keyword are now supported (*#2585*).

9) GCONINJE and GCONPROD keywords in the SCHEDULE section now support the RESV option for the TARGET parameter on both keywords (*#3363* and *#2476*).

10) The GCONINJE keyword with the addition of the RESV option, now supports all guide rate options via the GUIPHASE parameter (*#3363* and *#2476*).

11) The GPMAINT keyword is now supported which defines the groups under pressure maintenance control, the associated flow rate and pressure targets, and fluid in-place regions associated with pressure maintenance, as well as various pressure maintenance controls (*#3541*).

12) GRIDUNIT keyword in the GRID section is now supported (*#2588*).

13) Keywords MAPAXES and MAPUNITS are now supported in *.EGRID files (*#2617*).

14) Added the RPTSCHED reservoir volume report with the FIPRESV option on the keyword (*#3398*).

15) Various improvements to the restart file output to enable restarting from a restart file, including: sequential and parallel aquifer support (*#3474*), connection level cumulative volumes. Support for loading the ACTIONX and UDQ data from the restart file has also be implemented, although testing of this feature is limited as of this release (*#3543*). Well test data, as per the WTEST keyword, is now also written to the restart file (*#2718*).

B.4.3 IMPROVEMENTS

Improvements include:

1) Performance improvements in the both the standard and multi-segment well models by optimizing the potential calculation using BHP and THP (*#3524*).

2) Changed how inoperable wells are handled during well model iterations (*#3539*).

3) Performance improvements in reading and writing out binary files, that reduces load times of around 60% (*#2634*).

4) Improvements and corrections to the RESTART file for better compatibility with the commercial simulator (*#2714*), support for Group Guide rate values (*#2739*, *#2751* and *#3581*), and loading WTEST keyword associated data (*#3594*, *#2746* and *#2747*).

5) The code for handling the WTEST keyword in the well model model was improved by only opening wells that satisfy the economic conditions and that can physically flow (*#3547*, *#2737* and *#2744*).

6) Improved how the Guide Rate calculations are calculated for both groups and wells under guide rate control (*#2537* and *#2552*).

7) Various improvements to the parser in checking valid input to various keywords and the features supported by the keywords (*#2586*, *#2585*, and *#3440*).

In addition, the following new SUMMARY keywords are now recognized as described by the comments in Table B.8.

No.	Summary Keyword	Comment
1	CVPR, CVPT, CVIR and CVIT	Added support for the connection reservoir voidage volume summary vectors CVPR (production rate), CVPT (cumulative production total), CVIR (injection rate), and CVIT (cumulative injection total).
2	FOIPR, FWIPR, FGIPR, and FRPV	Added support for the Field Reservoir (conditions) Pore Volume (FRPV) vector, as well as the compositional oil, water and gas fluid in-place vectors FOIPR, FWIPR, and FGIPR. that are reported at reservoir conditions, as oppose to FOIP, FGIP and FWIP that are reported at surface conditions (*#2701*).
3	FGLIR, GGLIR, and WGLIR	Implemented support for gas lift variables. Note that the WALQ is also written out but all the values are zero (*#2495*).
4	FSIP	Added support for the Field Salt In-Place vector (*#3493*).

No.	Summary Keyword	Comment
5	FTIC, FTIR FTIT, FTPC, FTPR, and FTP	Implemented support for field tracer variables (*#3430*).
6	MSUMBUG MSUMCOMM MSUMERR MSUMMESS MSUMPROB MSUMWARN NEWTON	In the 2021-04 release the message keywords were recognized by the parser; however, no data associated with these vectors is written to file (*#2234*). This is still the case.
7	RPTONLY RPTONLYO	Added support for SUMMARY keywords that activates (RPTONLY) and deactivates (RPTONLYO) summary output at report time steps only. The keyword works in both the SUMMARY and SCHEDULE sections (*#2597* and *#2761*).
8	SUMTHIN	Implemented support for the SUMTHIN keyword that defines a time interval for writing out the SUMMARY data to the SUMMARY file and the RSM file. The keyword works in both the SUMMARY and SCHEDULE sections (*#2489*, *#2596*, *#2489* and *#2761*).
9	SWCT	The water cut vector for Multi-Segment Well segments has now been implemented (*#2636*).
10	WTIC, WTIR, WTIT, WTPC, WTPR, and WTPT	Implemented support for well tracer variables (*#3430*).
11	WWIRT	In the 2021-04 release support for the WWIRT vector for writing out the water injection rate target was implemented (*#2071*); however, the field (FWIRT) and Group (GWIRT) are still not available. This is still the case.

Table B.8: New SUMMARY Keywords for the 2021-10 Release

B.4.4 Bug Fixes

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

1) Previously, if the ACTNUM keyword was not supplied in the input deck when using the GDFILE keyword to define the grid, then the simulator would abort with a segmentation fault, even though the ACTNUM keyword is optional. This has now been corrected in this release (*#2675*).

2) Fixed a bug in RESTART output when using the FREQ=x option on the RPTRST keyword. which caused the output to the restart file to be based on calendar time instead of simulation time. For example if x was set to six, then the RESTART records were written January and July, instead of every six months of simulated time. This has now been fixed in this release (*#2551*).

3) OPM Flow does not support the SAVE file format but instead writes out a RESTART file record instead at the requested time. However, the RESTART record was written at the $TSTEP_{n+1}$ instead of $TSTEP_n$, this has now been changed so that the RESTART record is written at $TSTEP_n$, the same as the commercial simulator's equivalent SAVE file output (*#2661*).

4) Corrected an issue for when a region has zero active cells, when calculating the average region properties (*#3514*).

5) Fixed an issue with wells shut-in for the *norne 4_MSW* test case which may impact user's cases (*#3481*).

6) Previously the IMPORT keyword could not utilize the directory path declared via the PATHS keyword, this has now been rectified (*#2600*).

7) Fixed and issue when there are unknown keywords and the parser throws an exception in sequential runs and a segmentation fault in parallel runs (*#3503*).

8) Production and injection cumulative volumes were not necessary correct if wells changed from being a producer to an injector or vice versa. This has now been corrected (*#2581*).

9) Fixed an issue in parallel runs when initially all connections are close for a well (*#3495*).

10) Fixed a bug on the FIP report so that the PORV and TOTAL PORE VOLUMES values are the same as the commercial simulator, previously there were small discrepancies (*#3398*).

11) Reverted some changes on how the FACTOR (efficiency factor) parameter is applied on the GEFAC keyword in the SCHEDULE section. Now FACTOR is only applied while accumulating rates from subordinate groups (*#3464*).

12) Fixed a bug associated with the writing out of SUMMARY variables to the SUMMARY and RSM files referencing the first simulation date as oppose to the start of simulation date as per the START keyword (*#2685*).

13) Various ACTIONX keyword improvements and fixes, including:

    a) Verifying that the ACTIONX parameters and dimensions are consistent with the values entered on the ACTDIMS keyword in the RUNSPEC section. Previously, if the ACTDIMS parameters were inconsistent with the ACTIONX parameters OPM Flow would abort (*#2695*).

    b) For the ACTIONX date parameter MNTH, an error would occur if the month was enclosed in quotes, now both quoted ('JAN') and unquoted (JAN) values for MNTH are accepted (*#2696*).

    c) Numerical values for the ACTIONX date parameter MNTH are now also accepted. The values will be rounded to the nearest integer. So a MNTH value of 4.4 would result in the month being APR for April (*#2699*).

    d) Ensuring that matched wells are passed to WCONPROD and WCONINJE keywords using the '?'' string as the well name (*#2753*).

14) If the WTEST keyword was activated and opened a well to flow, then the well status remained unchanged, instead of being updated to open. This has now been rectified for this release (*#3537*).

15) Previously, the numerical aquifer keywords AQUCON and AQUNUM were incorrectly reported as unsupported. This has now been corrected in this release (*#3230*).

16) In the previous release, if the aquifer summary variables ANQR, ANQP and ANQT used the default version of the keywords, that is:

    ANQR
    /

    then the vectors were not written out. This has now been rectified in this release (*#2474*).

    Note that the FNQR and FNQT keywords are unsupported and a corresponding warning message is issued.

17) Hitherto the COPYREG keyword was reported as unsupported but was in fact supported and functioning. The incorrect unsupported message no longer occurs in this release (*#3234*).

18) In the SOLUTION section the RPTSOL keyword was up to now marked as active and was treated as such by the simulator; however, no output was generated in the print file. The keyword is now

labeled as unsupported (*#3248*). Note this is the print keyword for the SOLUTION section, and should not be confused with the SCHEDULE section print keyword RPTSCHED.

19) Rectified several issues with the GCONINJE re-injection options and fixed several well modeling bugs that caused the simulator to crash (*#2708*, *#3546* and *#2666*).

20) When running the carbon dioxide (CO_2) storage model, activated by the CO2STORE keyword in the RUNSPEC section, in parallel, the simulator would deadlock due to passed parameters being unreasonable. The deadlock has now be fixed for this release and error trapping is now the same as per a serial run. (*#3545* and *#3556*).

21) In CO_2 sequestration runs, activated by the CO2STORE in the RUNSPEC section, that typically model large time steps, the reported dates were inaccurate, this has now been rectified (*#3560*).

22) Corrected an error in restart runs for history matching wells. Previously, the wells used the default value of one atmosphere for the BHP instead of the actual BHP value in the restarted run, which resulted in numerical issues (*#2715*).

23) For the WECON keyword in the SCHEDULE section, the units for GOR and WGR parameters caused the well to prematurely shut-in, this has now been corrected. (*#2726*). Also fixed an issue with completions not being opened after a well event (*#3563* and *#2723*) and how the WTEST keyword in the SCHEDULE section was handled by the simulator (*#2720*).

24) Fixed an issue with aquifer connections in parallel runs (*#3572*).

25) Corrected how aquifer connections and MINPV interact so that only active cells are connected to the aquifer (*#2730* and *#2734*).

26) Fix an issue with writing out tracer data to the restart file for time steps that are not report time steps (*#3606*).

27) Fix several issues with well operability that caused wells to be shut-in (*#3569*) and for history match wells that cannot produce terminating the run prematurely (*#3607*).

28) In the radial model there was a bug that caused all the radial cells in the grid having a zero thickness, this has been addressed in this release (*#2640*)

29) Previously, both the GLIFTOPT and NETWORK keywords were reported as unsupported when in fact they were supported and fully functional. This has now been fixed for this release (*#3280*).

B.4.5 KNOWN ISSUES

1) 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.

2) Although the SUMMARY vector WALQ is written out all the values are zero.

3) 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.

4) Currently two phase gas-water and single phase water models only work with Enumeration Initialization.

5) For the saturation tables (SWOF, SWFN etc.) if the capillary pressure values were defaulted with 1* then the simulator should use linear interpolation to calculate the defaulted values. This is no longer working.

6) 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.

7) Using the GRAVITY keyword in the PROPS section will cause an exception to be raised and the simulator to abort. Use the DENSITY keyword instead to avoid this error.

8) As per the previous releases, the RPTSCHED WELLS sub-report does not print the FIELD group production data.

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.

10) OPM Flow does not support the SAVE file format for fast restarts like the commercial simulator, but instead writes a standard RESTART record at the requested time step in the SCHEDULE section. If the keyword is encountered in the RUNSPEC section it is ignored. However, the simulator issues a false warning saying the keyword is not supported, when in fact RESTART records are indeed written out in the SCHEDULE section if requested by the SAVE keyword.

11) Gas lift optimization currently only works for cases that have the gas phase present, that is runs with dead oil and no gas phase will cause the simulator to throw an exception (*#3658*).

12) For the UDQ ASSIGN operator after the terminating "/" normally any comments can be entered; however, if there is "/" within the comment field, as per:

<div style="color:maroon">ASSIGN FUNGLYLD 1.196   /   Condensate Yield (63.5/56.7)/(1.0 – 0.065)</div>

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

<div style="color:maroon">ASSIGN FUNGLYLD 1.196   / -- Condensate Yield (63.5/56.7)/(1.0 – 0.06)</div>

13) 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.

14) Currently, gas tracers cannot be used if the dissolve gas phase, as per the DISGAS keyword in the RUNSPEC section, is active in the model.

B.5 Release 2021-04

The 2021-04 release consists of some new features and various improvements and bug fixes. Highlights for this release includes support for numerical aquifers, gas lift optimization, network models, spider grids and support for diffusive flow for carbon dioxide storage, as well as convective dissolution of carbon dioxide into in situ brine.

B.5.1 New Command Line Options

The major command line made to this release are summarized in Table B.9

No.	Variable Name	Description	Default
	OPM Flow 2021-04 Major Command Line Option Changes		
1	-h or --help	A character string that causes OPM Flow to print a help message that gives a brief description of the available command line parameters. **This now only prints the active user facing command line options.**	N/A
2	--help-all	Prints all the command line options included in the release, including obsolete, hidden and deprecated options.	N/A
3	--allow-distributed-wells	Allow the perforations of a well to be distributed across multiple processes in parallel runs.	false
4	--opencl-ilu-reorder	A defined character string that selects the reordering strategy for ILU for openclSolver and should be set to: 1) "level_scheduling", or 2) "graph_coloring" Note that "level_scheduling" behaves like Dune and cusparse, whereas "graph_coloring" is more aggressive and is likely to be faster, but is random-based and generally increases the number of linear solves and linear iterations significantly.	"graph_coloring"
5	--vtk-write-diffusion-coefficients	A Boolean value that switches on (true) or off (false) the output of the molecular diffusion coefficients to the VTK[353] output files.	false
6	--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
7	--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

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[353] *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.*

OPM Flow 2021-04 Major Command Line Option Changes			
No.	Variable Name	Description	Default
8	--zoltan-imbalance-tol	A real positive that defines the tolerable imbalance of the load balancing provided by Zoltan package.	1.1

Table B.9: OPM Flow 2021-04 Major Command Line Option Changes.

B.5.2 NEW SIMULATOR FEATURES AND IMPROVEMENTS

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

15) Gas Lift Optimization: Added support for gas lift optimization, including in parallel, that enables the simulator to optimize allocate gas lift to wells and groups.

16) Numerical Aquifers. Added support for numerical aquifers that allow for flexible and efficient inclusion of pressure support from adjacent aquifers. Analytical aquifers have been supported in previous releases. See the AQUNUM and AQUCON keywords in the GRID section

17) Support for aquifers in MPI runs, that is in parallel runs.

18) Support for wells split between several process domains. This potentially gives better parallel grid partitioning. The well split is only implemented for standard wells, not for multi-segment wells; although the latter may be implemented in a future release.

19) Added guide rate support for injection groups via the GCONINJE keyword in the SCHEDULE section using the GRPGUIDE and GUIPHASE parameters on the keyword. Only the RATE, NETV and VOID guide rate options are supported.

20) Network Option. Implemented the Network option that allows for well/group coupling through common tubing head pressures when required.

21) Previously in an ACTIONX block only a subset of the well keywords could be used in the SCHEDULE section, this has now been extended to include the GCONPROD, GCONINJE and GLIFTOPT group keywords.

22) ACTIONX block can now handle well lists declared via the WLIST keyword for well keywords that are available within an ACTIONX block.

23) ACTIONX User Defined Quantity ("UDQ") can now be used for the artificial lift quantity on the WCONHIST and WCONPROD keywords in the SCHEDULE section, the ALQ-WELL parameter on the aforementioned keywords.

24) Expanded possible actions in ACTIONX block, including the use of the WELPI keyword parameter and UDQ updates.

25) Implemented convective DRSDT for CO_2 storage as described by Sandve at al.[354]. The convective DRSDT is activated with the DRSDTCON keyword in the SCHEDULE section.

26) Added experimental support for diffuse flow via the DIFFC and DIFFUSE keywords, this facility is not available via OPM Flow but can be accessed via re-compiling the source code with the option enabled. Due to the experimental nature of this feature and the unavailability in the released binary packages, the keywords and the functionality are not documented in this release of the manual.

27) Added support for the WELPI keyword for well productivity based scaling of a well's connection transmissibility factors.

28) Three-point vertical scaling of relative permeability functions (keywords KRGR, KRORG, KRORW, and KRWR).

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[354] *Tor Harald Sandve1, Sarah E. Gasda, Atgeirr Rasmussen, and Alf Birger Rustad. Convective dissolution in field scale CO_2 storage simulation using the OPM Flow simulator. Submitted to TCCS 11 – Trondheim Conference on CO_2 Capture, Transport and Storage Trondheim, Norway – June 21-23, 2021.*

29) Support for well and group names with more than eight (8) characters in summary output.

30) Added support on the WECON keyword in the SCHEDULE to apply the economic limit test using a well's potential, previously only the default of using a well production rate was implemented.

31) Support for IMPORT keyword in GRID section.

32) Added support for Python to access the PORO array.

33) Added support for SPIDER grids. The SPIDER keyword activates the radial grid geometry option for the model using Cartesian coordinates, if this keyword and the RADIAL keyword are omitted then Cartesian geometry is assumed by OPM Flow. This keyword will create a spiderweb-shaped grid based on a corner-point grid using the standard radial grid keywords: INRAD, DRV, DTHETAV, DZ/DZV etc. in the GRID the section. In addition the PERMR and PERMTHT keywords for radial and spider grids are now supported.

34) Added support for the multi-segment well keyword WSEGAICD that incorporates an autonomous inflow control device in a multi-segment well.

35) Continued improving OPM Flow's restart capability inline with the commercial simulator's functionality, including obtaining the restart point based on TSTEP in addition to the DATES keyword time steps.

In addition, the following new SUMMARY keywords are now recognized as described by the comments in Table B.10.

No.	Summary Keyword	Comment
1	AAQTD AAQPD	Added support for the AAQTD and AAQPD vectors in the SUMMARY section, for calculating and reporting the dimensionless time (simulator time divided by aquifer's time constant) and pressure (influence function evaluated at dimensionless time) values as part of the Carter-Tracy aquifers.
2	BKROG BKROW	Added support for the BKROG and BKROW vectors that output the block-level values of the relative permeability of oil in the two-phase oil/gas and oil/water subsystems of a three-phase simulation run.
3	BSOIL BSGAS BSWAT BPRESSUR	Added support for SUMMARY variables BSOIL, BSGAS, BSWAT, and BPRESSUR as aliases for BOSAT, BGSAT, BWSAT, and BPR respectively.
4	CORPL COFRL	Added CORPL and CORFL as as aliases for WOFRL for a well's completion oil rate.
5	RHPV	Added RHPV vector, a regions hydrocarbon pore volume, to the SUMMARY section variables.
6	WEPR WEPT	Added support for the WEPR and WEPT energy vectors in the SUMMARY section.
7	WWIRT	Added support for the WWIRT vector in the SUMMARY section for writing out the water injection rate target. Note that the field (FWIRT) and Group (GWIRT) are still not available.

No.	Summary Keyword	Comment
8	MSUMBUG MSUMCOMM MSUMERR MSUMMESS MSUMPROB MSUMWARN NEWTON	The message keywords are now recognized by the parser; however, no data associated with these vectors is written to file. Previously these keywords would cause an error and the simulator would stop due to the error.

Table B.10: New SUMMARY Keywords for the 2021-04 Release

B.5.3 BUG FIXES

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

1) Various fixes for thermal simulations, including how the thermal conductivity was calculated in thermal runs, now the thermal conductivity is calculated in the same manner as permeability and diffusivity.

2) Fixes in the GCONINJE implementation.

3) On both the GCONPROD and GCONINJE keywords in the SCHEDULE section, the GRPCNTL property sets if a the group is subject to higher level group control or not. If the group being defined is the FIELD then GRPCNTL is supposed to be ignored, this was previously not the case. This has now been corrected.

4) Fixes in the boundary setup when using the OPM specific BC keyword.

5) Correct inclusion of the group efficiency for the top group level

6) Improved convergence of the multi-segmented well equations.

7) Various MPI related fixes, avoiding dead-locks etc.

8) Corrected various issues with the UDQ facility, including when the UDQ keyword contains both ASSIGN and DEFINE statements such that only the ASSIGN should be only be evaluated for the first time step, and then in consecutive time steps the DEFINE statement should be executed. Also when a UDQ expression refers to other UDQ's the previous value for the other UDQ's should be used when evaluating the expression.

9) Fixed an error in the processing of the COPYREG keyword due to picking up the wrong item; however, COPYREG keyword is reported as unsupported but is in fact supported and functioning.

10) Corrected various issues with well reference depths used to report BHP, so that the reference depth is <u>not</u> updated when new connections are added via the COMPDAT keyword, but <u>is updated</u> when the WELSPECS keyword is introduced.

11) Fixed an error with the CO2STORE keyword being reported as unsupported. The keyword is now recognized and functioning.

12) Fix a bug that causes the simulator to throw an exception if the SUMMARY temperature keywords were used (WBHPT, FTIRHEA, etc.) and were not recognized by the parser.

13) Fixed a bug with the WTICHEA and WTPCHEA variables in the SUMMARY section not reporting the correct temperatures. Now the temperature as set by WTEMP is reported for the injector, which is consistent with the commercial simulator. For non-thermal decks both injectors and producers now report the standard condition temperature of $60°$ F or $15.56°$ C, depending on the units being used. For thermal decks the producers report the temperature at same reference depth as the BHP and the bottom-hole temperature is now calculated.

14) Fix an error associated with the number of FIPNUM regions and the SUMMARY file output associated with using the general form of the region summary vectors, that is:

RPR
/

as opposed to declaring the region format.

RPR
1 2 /

15) The issue with the ALL keyword in the SUMMARY section that reports "*Warning: Unhandled summary keyword ALL*" multiple times has been fixed. The message now states the actual summary vector associated with the ALL keyword that is not available, instead of stating the actual ALL keyword.

16) If gas lift optimization was not used the simulator did not use the ALQ value on the WCONPROD keyword as the default value, this has now been fixed.

17) A bug that caused the simulator to throw exception when the depth on the SALTVD table did not cover the depth range of the model has been fixed.

18) Previously the SUMMARY vector ROEW, that is a regions oil recovery factor, was based on a well's production total (WOPT), this has now be changed to be based on a well's completion total (COPT) instead, as it was not obvious how to assign wells to regions.

19) Fixed an error in the ALQ calculation for injected gas lift that used rate instead of volume in the calculation.

20) Added the unused commercial compositional simulator's threshold saturation of Killough's hysteresis model to the EHYSTR. The parameter is not used by OPM Flow.

21) As per the previous releases, two phase gas-water models (GAS and WATER only keywords in the RUNSPEC section) will not initialize in OPM Flow. Previously, the simulator would throw an exception, this is now trapped and a message is issued stating the gas-water systems are not currently supported. The work around is to convert the model to a three phase model (OIL, GAS and WATER keywords in the RUNSPEC section) and modify the PROPS section PVT keywords accordingly.

22) Previously the OPERATE keyword EQUATION options of MAXLIM and MINLIM were not supported, this has been rectified for this release and both options are now fully supported.

B.5.4 KNOWN ISSUES

1) The numerical aquifer keywords AQUCON and AQUNUM are incorrectly reported as unsupported. This has already been corrected in the current MASTER, so will be fixed in the next release.

2) The aquifer summary variables ANQR, ANQP and ANQT variables are supposed to be supported and simulator does not issue a warning message if these keywords are in the input deck. However, the output from these keywords is not written to the SUMMARY or RSM file. if the default version of the keywords are used, that is:

ANQR
/

will not work, but specifying the aquifer numbers will work, so for aquifer number one we would use:

ANQR
1 /

Note that the FNQR and FNQT keywords are unsupported and a corresponding warning message is issued.

3) The COPYREG keyword is reported as unsupported but is in fact supported and functioning. The issue has been corrected for the next release.

4) In the SOLUTION section he RPTSOL keyword is marked as active and is treated as such by the simulator; however, no output is generated in the print file. The keyword should be labeled as inactive. Note this is the print keyword for the SOLUTION section, and should not be confused with

the SCHEDULE section print keyword RPTSCHED. The issue has been corrected for the next release.

5) Using radial grids via the RADIAL keyword in the RUNSPEC section will cause the simulator to throw an exception as radial grids are not included in the release. Instead one can use the SPIDER grid keyword for radial flow simulation that converts the radial entered keywords to Cartesian coordinates using Irregular Corner-Point Grid – see the example in the section on SPIDER grids (*Spider Grids*).

6) For radial grids the COORDSYS keyword item three must be set to COMP to complete the circle, this has not been implemented in this release.

7) Both the GLIFTOPT and NETWORK keywords are reported as unsupported when in fact they are supported and fully functional. This has already been fixed for the next release.

8) Using the GRAVITY keyword in the PROPS section will cause an exception to be raised and the simulator to abort. Use the DENSITY keyword instead to avoid this error.

9) As per the previous releases, the Tracer model is not working. In order to activate the Tracer model the command line variable *-enable-tracer-mode* should be set to "true"; the simulator will still issue a message saying *Warning: Keyword 'TRACERS' is not supported by flow* but will continue to run. However, the results from the tracer tracking appear to be incorrect and should not be relied upon. The standard results, rates, pressures, saturations, etc., are identical to the comparable no tracer run.

10) As per the previous releases, the RPTSCHED WELLS sub-report does not print the FIELD group production data.

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B.6 Release 2020-10

Since the OPM 2020.04 release in May 2020 the developers have worked on many aspects of the simulator, with a particular focus on prediction mode abilities and expanding support for user-defined quantities and dynamic actions (ACTIONX keyword). The project team have also added specialized physics models including Brine and CO_2 storage capabilities as well as two experimental accelerators for the linear solvers based on OpenCL and CUDA for GPU calculations.

B.6.1 New Output Files and Command Line Options

The following new out files and command load options have been implemented in this release:

1) Add a new output file, *.INFOSTEP, that contains per time step performance numbers, that is the number of linear solves, number of linear iterations, setup time, etc.

2) Improve efficiency in loading summary files, especially to support manipulating summary data from Python wrappers. This also includes a new special purpose utility, called "make_lodsmry", that creates files named *.LODSMRY which contains the summary vectors collected in the time direction for all values for one vector, before all values of another vector.

3) Exclusively use the "flexible" framework for selecting linear solvers, through the new command line option "--linsolver". The simulator supports the following pre-configured options:

   1) "ilu0",

   2) "cpr_trueimpes",

   3) "cpr_quasiimpes",

   4) "cpr" (alias for "cpr_trueimpes"), or

   5) "amg".

   Advanced users may alternatively select a runtime configuration represented in a JSON[355] file by passing a filename with the extension ".json". The default setting is "ilu0".

4) Added an option to use non-strict tolerances only if a small fraction of the total pore volume violates the strict tolerances. By default the simulator uses a non-strict pore volume threshold of 0.03 (3%), but this is configurable at run time with the new option '--relaxed-max-pv-fraction'.

5) Add new option ProjectSaturations (--project-saturations) which ensures all saturation values are in the interval (0, 1), including runs that use solvents.

6) Replaced the various –vtk-write command line options with one global option,--enable-vtk-output, that enables or disables the writing of VTK files.

B.6.2 New Simulator Features

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

1) Initial support for calling simulator time step functions from Python language wrappers have been implemented.

2) A new PVT model for CO_2 and brine has been implemented; see the C02STORE keyword in the RUNSPEC section and SALINITY keyword in the PROPS section.

3) Added support salt dependent water PVT properties, see the PVTWSALT keyword in the PROPS section and SALTVD keyword in the SOLUTION section.

4) Added support for using user defined arguments (UDAs) in the WELTARG and GCONPROD keywords.

---

[355] *JavaScript Object Notation is an open standard file format, and data interchange format, that uses human-readable text to store and transmit data objects consisting of attribute–value pairs and array data types.*

5) Implemented support for using SOF2 (Family II) with Family I (SGOF/SWOF) keywords in the case of three-phase solvent models.

6) Added support for well-level temperature summary output in thermal simulations (SUMMARY keywords WTICHEA and WTPCHEA). However, subsequent testing indicates that data written out is incorrect.

7) Implemented support gas lift optimization for standard (non-segmented) wells, see the LIFTOPT, GLIFTOPT and WLIFTOPT keywords in the RUNSPEC section.

8) Implemented support for field, group, and well level summary output of gas lift injection rates (keywords FGLIR, GGLIR, WGLIR in the SUMMARY section). However, although the keywords are recognized and the data written to the SUMMARY file, subsequent testing indicates all the values are zero.

9) Added summary output for analytical aquifers: AAQR, AAQT, and AAQP. Note that the following analytical aquifer summary keywords will be ignored: FAQR, FAQT, AAQTD and AAQPD.

10) Implemented the SUMMARY vectors FMWIA, FMWPA, GMWIA, and GMWPA for counting abandoned producers and injectors. The vectors can also written out via the FMWSET and GMWSET keywords in the SUMMARY section.

11) Incorporated the FILLEPS keyword in the PROPS section. Saturation function scaling end-points now also honor the TOLCRIT value defined by the TOLCRIT keyword when written to the *.INIT file.

12) Generalized the implementation of the FIP keyword and to handle the additional summary variables that include fluid in-place region name defined by a five character string following the FIP characters on the FIP keyword, FIP-BLK1 for example. This enables the regional properties for FIP-BLK1to be written to the SUMMARY file. For example to write the regional pressure for "-BLK1" one would use the SUMMARY keyword RPR-BLK1, where "-BLK1" can be any character string.

13) Improved the error messages from the initial input parsing of the input deck for great clarity and to better enable input deck validation.

14) Added support for group control targets/prediction mode with guide rates in the simulator (see the GUIDERAT keyword in the SCHEDULE section) that also incorporates voidage replacement and re-injection scenarios. Note that the simulator will erroneously report that the GUIDERAT keyword is not recognized, when in fact it is and will be used by the simulator.

15) Added support for outputting guide rate values at well and group levels to the SUMMARY files (summary keywords W*PGR and G*PGR).

16) Added the support for the GCONSALE keyword that defines group sales gas production targets and constraints for when the gas production from an oil field group is exported under a Gas Sales Agreement ("GSA") and the oil field group also has oil production targets and constraints. In addition the GCONSUMP keyword has been implemented that defines the group gas consumption (fuel) rate. Note again the simulator will erroneously report that the two keywords are not recognized, when in fact they are and will be used by the simulator. Secondly, the SUMMARY vectors associated with these keywords (FGSR, FGST, FGCR, FGCT, GGSR, GGST, GGCR, and GGCT) have not been implemented).

17) Added additional logging information to the *.PRT file for the setup phase of the simulator when processing the *.DATA file, including which keywords and their file locations are being processed at any one time. This is to assist the user in narrowing down problems in the input file.

18) Add support for editing transmissibility values in the EDIT section.

19) Add support for handling MULTZ in a pinched-out column of cells when the PINCH multiplier processing mode is 'ALL'.

20) Implemented a clean shutdown in a parallel simulation run if any process throws an exception.

21) Add support for running Zoltan[356] based partitioning on a single process only.

B.6.3 BUG FIXES

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

1) Fix a bug in parsing the UDQ keyword that caused the UDQ tokenizer to split on the '-' character when parsing numerical literals on scientific form: 1E-5.

2) Added the missing GLR_LIMIT to the WCUTBACK keyword, solving bug #1877.

3) The simulator now correctly handles the RPTRST keyword in SOLUTION section.

4) Removed OPERATER and OPERNUM keywords from the keywords not supported since they are supported.

5) Fix the default pressure initialization for Carter-Tracey analytical aquifers.

6) Fix the way the simulator incorporates the gravity terms in boundary conditions fluxes.

7) Fix bugs associated with the TRAN* series of keywords in EDIT section.

8) Ensure that VTK data set filenames use relative paths.

9) Various bug fixes for the Message Passing Interface ("MPI"). MPI is a standardized and portable message-passing system developed for distributed and parallel computing.

10) Fixes to the source building work flow, especially for the "opm-upscaling" module.

11) Fix a bug in the interaction of TUNING and WSEGITER. This was needed for compatible with the commercial simulator's restart feature.

12) The simulator issued a message "All completions in well XXX is shut at X.XXXXX days. The well is therefore also shut" multiple times, this has been fixed for this release.

13) Fixed missing tubing length data in the WELSPECS Multi-Segment Well Connection sub-report.

14) Previously OPM Flow incorrectly reported that the MAXVALUE keyword was not supported. The warning message was incorrect as the values entered on the keyword were applied to the named array. The warning message has been removed for this release.

15) Previously for the Brine model, the values entered via the SALTVD keyword were ignored and reset to zero. This has been fixed for this release.

16) Fixed an issue with the simulator failing to correctly read the RTEMP and RTEMPA keywords.

17) Added the following polymer model summary vectors to the SUMMARY file: FCIR, FCIT, FCPC, FCPR, FCPT, GCIR, GCIT, GCPC, GCPR, GCPT, WCIR, WCIT, WCPC, WCPR, and WCPT.

18) Fixed a bug with the standard usage of ROCKTAB and throw an exception on the more exotic usages that are unsupported.

B.6.4 KNOWN ISSUES

1) The simulator will throw an exception if the depth entries on the SALTVD table do not cover the range of the model depths, as this keyword currently not set up to extrapolate outside its domain of definition. The work around is to ensure the depths on the SALTVD keyword cover the depth range in the model.

2) The simulator may throw an exception if a SUMMARY keyword (WBHPT, FTIRHEA, etc.) is not recognized by the parser. The work around is to delete the offending keyword(s) from the input deck.

---

[356] *The Zoltan library is a toolkit of parallel combinatorial algorithms for unstructured and/or adaptive computations, for dynamic partitioning using graph coloring and ordering. In addition to native implementations of many algorithms, Zoltan interfaces to the graph and hypergraph partitioning libraries of PT-Scotch, PaToH and ParMETIS. See http://www.cs.sandia.gov/zoltan/ for further information.*

3) There is an issue with the ALL keyword in the SUMMARY section that reports "*Warning: Unhandled summary keyword ALL*" multiple times. The ALL keyword is handled by the simulator and the currently available supported summary vectors will be written out to the SUMMARY and RSM files (if requested). The message should state the actual summary vector associated with the ALL keyword that is not available, instead of stating the actual ALL keyword.

4) As per the previous release, two phase gas-water models (GAS and WATER only keywords in the RUNSPEC section) will not initialize in OPM Flow, this has been the status for past versions of the simulator as well. The work around is to convert the model to a three phase model (OIL, GAS and WATER keywords in the RUNSPEC section) and modify the PROPS section PVT keywords accordingly.

5) As per the previous release, the Tracer model is not working. In order to activate the Tracer model the command line variable *-enable-tracer-mode* should be set to "true"; the simulator will still issue a message saying *Warning: Keyword 'TRACERS' is not supported by flow* but will continue to run. However, the results from the tracer tracking appear to be incorrect and should not be relied upon. The standard results, rates, pressures, saturations, etc., are identical to the comparable no tracer run.

6) The OPERATE keyword EQUATION options of MAXLIM and MINLIM are currently not supported.

7) As per the previous release, the RPTSCHED WELLS sub-report does not print the FIELD group production data.

B.7   Release 2020-04

B.7.1   New Features

Writing out of the SUMMARY file data in a columnar format to the RSM file has been implemented. Normally the SEPARATE keyword in the SUMMARY section is invoked to direct the data stream to a separate RSM file for easy loading into other programs, for example, Microsoft's EXCEL or LibreOffice's CALC spreadsheet program. However, this is the default behavior for OPM Flow.

Additional SCHEDULE section reports has been added to this release including the WELLS and WELSPECS options on the RPTSCHED keyword. The reports are similar to those from the commercial simulator.

The Brine Tracking option has now been activated in this release and should be considered experimental and used with caution. The keywords associated with this feature are BRINE, BDENSITY, PVTWALT and WSALT.

A Python scripting facility has been implemented in OPM Flow via the:

1) PYINPUT/PYEND keywords that processes standard Python commands that can be used to manipulate and define the simulators input parameters during processing of the input deck. The main purpose of the facility is to script the construction of the various keywords.

2) PYACTION keyword that provides similar functionality as the ACTIONX scripting facility, but instead uses the standard Python interpreter. PYACTION provides an interface between the simulator and Python via a Python function that enables obtaining various run times parameters from the simulator.

Experimental support for using the Graphics Processing Unit ("GPU") *–cusparseSolver* as the linear solver has been implemented, see the command line parameter *–use-gpu* in section *2.2 Running OPM Flow 2023-04 From The Command Line*.

A command line parameter *--sched-restart* has been added to allow a restart run to initialize wells and groups from the historical SCHEDULE section (current and past default behavior), or from the well and group data on the RESTART file. Note that the commercial simulator always uses data from the restart file. The intention is to duplicate the behavior of the commercial simulator after suitable testing.

The initialization of parallel cases has been completely reworked, the simulator now uses considerably less memory when initializing a parallel run.

Group control of wells in prediction mode has been made more consistent and improved in several ways, this may impact the results compared to previous versions of the simulator.

All black-oil keywords are now documented to varying level of detail depending on the functionality implemented in OPM Flow, and all are now recognized by the OPM Flow input deck parser.

In addition the following new keywords are now recognized with varying functionality as described by the comments in Table B.11.

No.	Keyword	Comment
1	BDENSITY	Define the Surface Brine Density for the Fluid.
2	BRINE	Activate Brine Tracking Option.
3	DATE	Activate the DATE Option for the SUMMARY File.
4	EXIT	Exit Simulation from within an Action Section, this is an OPM Flow specific keyword.
5	PERMFAC	Permeability Factor Reduction Due to Salt Precipitation for OPM Flow's Salt Precipitation model.

No.	Keyword	Comment
6	PVTGW	Gas PVT Properties for Dry Gas with Vaporized Water for OPM Flow's Salt Precipitation model.
7	PVTGWO	Gas PVT Properties for Wet Gas with Vaporized Water and Oil for OPM Flow's Salt Precipitation model.
8	PVTWSALT	Define Brine Water Fluid Properties for Various Regions for the Brine Tracking and Salt Precipitation models.
9	PYACTION	Define Python Based Action Conditions and Command Processing
10	PYEND	End the Definition of a PYINPUT Section
11	PYINPUT	Define the Start of a PYINPUT Section
12	RUNSUM	Activate RSM File Output of the SUMMARY Data.
13	RWGSALT	Water Vaporization versus Pressure and Salt Concentration or OPM Flow's Salt Precipitation model.
14	SALTSOL	Define the Salt Solubility Limit for All Cells for OPM Flow's Salt Precipitation model.
15	SALTVD	Define the Equilibration Salt Concentration versus Depth Tables for the Brine model. Note: Although the data is read by the simulator it is currently ignored.
16	SEPARATE	Activate the Separate RSM File Output Option.
17	SKIPREST	Activate Skipping of Restart Schedule Data (this keyword is now functional, previously it was only recognized by the input deck).
18	WSALT	Define Water Injection Well Salt Concentrations.
19	WSEGVALV	Define Multi-Segment Well Sub-Critical Valve for Inflow Control Device

Notes:

1) Cells colored in green in the "No." column indicate that the keyword is recognized by the input deck parser and fully or partially supported by OPM Flow.

2) Cells colored in orange in the "No." column indicate that the keyword is recognized by the input deck parser but not supported by OPM Flow.

3) Cells colored in red in the "No." column indicate that the keyword is not recognized by the input deck parser and OPM Flow.

Table B.11: New Keywords for the 2020-04 Release

B.7.2 Bug Fixes

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

1) Fixed a bug with the PVTSALT keyword that caused the keyword to be set to unrecognized.

B.7.3 KNOWN ISSUES

1) Two phase gas-water models (GAS and WATER only keywords in the RUNSPEC section) will not initialize in OPM Flow, this has been the status for past versions of the simulator as well. The work around is to convert the model to a three phase model (OIL, GAS and WATER keywords in the RUNSPEC section) and modify the PROPS section keywords data accordingly.

2) OPM Flow incorrectly reports that the MAXVALUE keyword is not supported. The warning message is incorrect and the values entered on the keyword will be applied to the named array.

3) For the Brine model the SALTVD is active in this release; however, the values entered via the keyword are ignored and reset to zero. A fix is ongoing but did not make it into the 2020-04 release.

4) The Tracer model is not working. In order to activate the Tracer model the command line variable -enable-tracer-mode should be set to "true"; the simulator will still issue a message saying *Warning: Keyword 'TRACERS' is not supported by flow* but will continue to run. However, the results from the tracer tracking appear to be incorrect and should not be relied upon. The standard results, rates, pressures, saturations, etc., are identical to the comparable no tracer run.

5) The OPERATE keyword EQUATION options of MAXLIM and MINLIM are currently not supported.

6) The RPTSCHED WELLS report does not print the FIELD group production data.

B.7.4 DEVELOPER CHANGES

1) For restart runs the commercial simulator does not consider the historical part of the SCHEDULE section in the input deck, as all necessary well and group information is obtained from the restart file, and the interpretation of the SCHEDULE keywords starts at the restart date in the input deck. Historically, OPM Flow has treated restart runs differently. OPM Flow uses the SCHEDULE section data to initialize the wells and groups, combined with the solution arrays (PRESSURE, SWAT, etc.) from the restart file. There is an ongoing effort to duplicate the same behavior as the commercial simulator to further increase the compatibility between the commercial simulator and OPM Flow. This work is being done in stages to ensure existing models continue to work. See the --sched-restart command line parameter in section *2.2 Running OPM Flow 2023-04 From The Command Line*.

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B.8 RELEASE 2019-10

B.8.1 NEW FEATURES

An experimental foam module has been added to OPM Flow 2019-10 release. With this it is possible to simulate certain types of surfactant injection. Such injection stimulates formation of foam to change mobility ratios, and give better reservoir sweep. The implemented foam model treats surfactant transported in the gas phase, and reduces the mobility of that phase depending on the surfactant concentration. In addition to mobility reduction, adsorption to the reservoir rock is included in the model. To test the foam module use the keywords, FOAM, FOAMADS, FOAMMOB, FOAMOPTS, FOAMROCK and WFOAM. The model has not been tested on anything but artificial test cases so far, it is therefore likely to have omissions and bugs. If you try it out, please send feedback by the mailinglist (*opm-request@opm-project.org*), or by raising an issue on GitHub (*https://github.com/OPM*). A simple test case based on SPE1 has been added to the opm-tests repository, in the directory spe1_foam (*https://github.com/OPM/opm-tests/tree/master/spe1_foam*).

First implementation of the ACTIONX facility and associated keywords. The ACTIONX keyword defines a series of conditions that invoke run time processing of ACTION functions and is similar to executing a run time script. This is the general purpose version of the ACTION series of keywords that can apply Boolean conditional tests to variables at the field, group, region, well segment and well levels. The ACTION, ACTIONG, ACTIONR, ACTIONS and ACTIONW keywords are not implemented in OPM Flow and are unlikely to be so, as the ACTIONX keyword implements their functionality with greater flexibility. As this is the first release with this functionality, users should exercise caution using this functionality.

Rock compaction has been implemented via the OVERBURD, ROCK2D, ROCK2DTR, ROCKCOMP, and the ROCKNUM keywords. The facility is activated by the ROCKCOMP keyword in the RUNSPEC section.

OPM Flow now supports output of a common subset of end-point arrays to OPM Flow's *.INIT file. Specifically, OPM Flow outputs the drainage and imbibition curve end-points but does not currently support directionally dependent end-points (e.g., SGCRX-). This version also supports the FILLEPS keyword to output the actual end-points, whether taken from direct assignment in the deck or derived from the corresponding saturation function table. Note that OPM Flow does not currently support the TOLCRIT keyword which will affect *CR end-points derived from the tables. This version also activates the pertinent flags in the *.INIT file's LOGIHEAD vector which means that the ResInsight relative permeability plot is now able to distinguish the scaled from the unscaled curves in a cell even for result sets generated by OPM Flow.

Initial implementation of the well list facility via the WLIST keyword for static well lists has been incorporated into this release. In addition, improve support for the WTEST keyword has been added and the WECON keyword now supports GOR checking.

The issue with the Ubuntu Linux 18.04 LTS (64-bit version only) release that prevented mpirun working with OPM Flow under this version of the operating system has been resolved in this release of OPM Flow.

There is an on going effort to recognize all known black-oil keywords by the OPM Flow input deck parser, and to document all these keywords with varying level of detail depending on the functionality implemented in OPM Flow.

In addition the following new keywords are now recognized with varying functionality as described by the comments in Table B.12.

No.	Keyword	Comment
1	ACTION	Define Action Conditions and Command Processing (Field).
2	ACTIONG	Define Action Conditions and Command Processing (Groups).
3	ACTIONR	Define Action Conditions and Command Processing (Regions).
4	ACTIONS	Define Action Conditions and Command Processing (Well Segments).
5	ACTIONW	Define Action Conditions and Command Processing (Wells).

No.	Keyword	Comment
6	ACTIONX	Define Action Conditions and Command Processing.
7	ACTPARAM	Define Action Facility Target and Tolerance Parameters.
8	ENDACTIO	End the Definition of ACTION Commands.
9	UDADIMS	Define the Dimensions of the User Defined Arguments.
10	UDQ	Declare User Define Quantities ("UDQ").
11	UDQDIMS	Define the Dimensions of the User Defined UDQ Feature.
12	UDQPARAM	Define Parameters for the User Defined Quantity Feature.
13	UDT	Declare User Define Tables ("UDT").
14	UDTDIMS	Define the Dimensions of the User Defined Tables.
15	FILLEPS	Activate Saturation End Point Export to INIT File.
16	FOAM	Activate the Foam Phase and Model.
17	FOAMADS	Define Foam Rock Adsorption Tables.
18	FOAMDCYO	Define Foam Decay versus Oil Saturation Tables.
19	FOAMDCYW	Define Foam Decay versus Water Saturation Tables.
20	FOAMFCN	Define Foam Gas Mobility Reduction versus Capillary Number.
21	FOAMFRM	Define Foam Gas Mobility Reduction versus Reference Mobility.
22	FOAMFSC	Define Foam Gas Mobility versus Surfactant Concentration Functions.
23	FOAMFSO	Define Foam Gas Mobility Reduction versus Oil Saturation.
24	FOAMFST	Define Foam Gas-Water Surface Tension versus Surfactant Concentration.
25	FOAMFST	Define Foam Gas-Water Surface Tension versus Surfactant Concentration.
26	FOAMMOB	Define Foam Gas Mobility versus Foam Concentration Tables.
27	FOAMMOBP	Define Foam Mobility Reduction versus Oil Pressure.
28	FOAMMOBS	Define Foam Mobility Reduction versus Shear.
29	FOAMOPTS	Define Foam Model Options.
30	FOAMROCK	Define Foam Rock Properties.
31	OVERBURD	Define Rock Overburden Pressure versus Depth Tables.
32	ROCK2D	Pore Volume Compaction versus Pressure and Sw Tables.
33	ROCK2DTR	Transmissibility Compaction versus Pressure and Sw Tables
34	ROCKCOMP	Activate Rock Compaction.
35	ROCKFRAC	Define the Rock Volume to Bulk Volume Fraction for All the Cells.
36	ROCKNUM	Define Rock Compaction Table Region Numbers.

No.	Keyword	Comment
37	ROCKOPTS	Define Rock Compaction and Compressibility Options.
38	ROCKPAMA	Define Coal Palmer-Mansorri Rock Model Parameters.
39	ROCKTAB	Rock Compaction Tables.
40	ROCKTABH	Rock Compaction Hysteresis Tables.
41	ROCKTABW	Rock Compaction Tables (Water Induced).
42	ROCKWNOD	Water Saturation Values for Compaction Pressure-Sw Tables.
43	WFOAM	Define Well Foam Injection Concentrations.
44	WLIST	Define Well Lists (Static).
45	WLISTARG	Modify Well List Target and Constraint Values (Static).
46	WLISTNAM	Define Well Lists (WLISTARG).

Notes:

1) Cells colored in green in the "No." column indicate that the keyword is recognized by the input deck parser and fully or partially supported by OPM Flow.

2) Cells colored in orange in the "No." column indicate that the keyword is recognized by the input deck parser but not supported by OPM Flow.

3) Cells colored in red in the "No." column indicate that the keyword is not recognized by the input deck parser and OPM Flow.

*Table B.12: New Keywords for the 2019-10 Release*

B.8.2 BUG FIXES

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

1) Restart values on the RESTART file are now only read once, previously this was done twice.
2) Fixed several bugs concerning the input and output of RESTART files.
3) EBOS now logs output to both the *.PRT and *.DBG files.
4) OPM Flow now abort a run without reading the deck if the command line parameters are incorrect.
5) Use grid region mapping from opm-grid.
6) Fixed a bug related to negative THP values when extrapolating values from VFP tables.
7) Printing of logging information from Well Testing is now written to both the *.PRT and *.LOG files.
8) Several bug fixes to multi-segement well model have been implemented.
9) Both the *.INIT and *.GRID files are now written out on a restart run.
10) OPM Flow now does not update RESV variable for producers in prediction mode.
11) Fixed an issue with the simulator over writing the FPR summary vector instead of writing out the FPRP summary vector instead..
12) The simulator now always writes out the transmissibilities between vertical neighbors to TRANZ (even for non-neighbor connections).

B.8.3 DEVELOPER CHANGES

For the 2019-10 release, the module "ewoms" has been renamed "opm-models". The repository on github has been renamed, but the old name will continue to work for some time. The figure below shows the current module structure for the 2019.10 release.

Figure B.3: Module Structure for 2019-10 Release
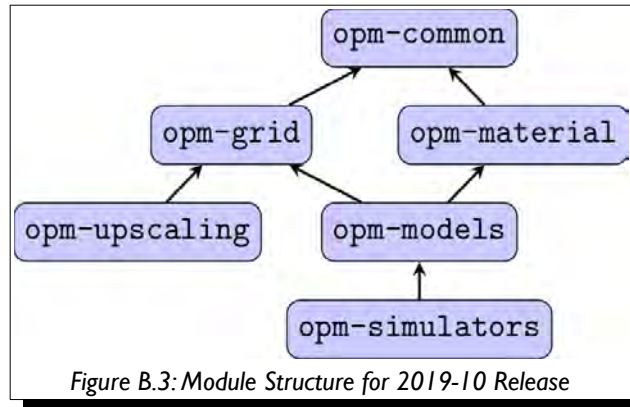
Most files/header that were located in directory opm/autodiff in opm-simulators have been moved to opm/simulators/aquifers, opm/simulators/linalg, opm/simulators/utils, or opm/simulators/wells depending on their content.

Markus Blatt, Atgeirr Flø Rasmussen, Bård Skaflestad, Tor Harald Sandve, Arne Morten Kvarving and David Baxendale.

B.9 RELEASE 2019-04

Error message reporting has been significantly improved for this release. Previously, when OPM Flow found an error in the input deck, an exception was thrown immediately and the program terminated after writing out an error message. In many cases there are multiple errors in an input deck, but only the first will be reported. In this release all errors are collected and OPM Flow continues until the input deck has been completely assembled. If there have been errors during processing all error messages are now written to the standard output files, after which the program will terminate. This should greatly improve debugging of OPM Flow input deck. The feature is activated by the command line option:

<p style="text-align:center; color:red">flow --strict-mode=true CASE.DATA</p>

See section *2.2Running OPM Flow 2023-04 From The Command Line* for additional information.

In addition the following new keywords are now recognized with varying functionality as described by the comments in Table B.13.

No.	Keyword	Comment
1	AQUFETP	The AQUFETP keyword defines Fetkovich Analytical aquifers and the aquifer properties.
2	DRSDTR	DRSDTR defines the maximum rate at which the solution gas-oil ratio (Rs) can be increased in a grid cell for various regions in the model.
3	DRVDTR	DRVDTR defines the maximum rate at which the solution oil-gas ratio or condensate-gas ratio (Rv) can be increased in a grid cell for various regions in the model.
4	FILEUNIT	The FILEUNIT keyword defines the units of the of the data set, and is used to verify that the units in the input deck and any associated include files are consistent grid data.
	GDFILE	The GDFILE keyword loads a GRID file that contains the structural data for the grid as a set of topological cuboidal cells, and EGRID files that contain structural and property data. Added in 2018-10 but didn't work, this has been fixed in 2019-04 and is fully functional.
5	FLUXTYPE	Recognized by the input deck parser only.
6	ISGLPC	ISGLPC defines the <u>imbibition</u> connate gas saturation for all the cells in the model via an array when the end-point scaling option has been invoked. Recognized by the input deck parser, and internalised into OPM Flow's 3D property representations. <u>Missing Some Functionality - Use with Caution.</u>
7	ISWLPC	ISWLPC defines the <u>imbibition</u> connate water saturation for all the cells in the model via an array when the end-point scaling option has been invoked. Recognized by the input deck parser, and internalised into OPM Flow's 3D property representations. Missing some functionality. <u>Use with caution</u>.
8	MULTIN	This keyword switches on the Multiple Input Files option for all input files.
8	MULTOUT	This keyword switches on the Multiple Output Files option for all output files.
9	OVERBURD	Recognized by the input deck parser and simulator support is available in the experimental "ebos" simulator.
10	ROCK2D	Recognized by the input deck parser and simulator support is available in the experimental "ebos" simulator.

No.	Keyword	Comment
11	ROCK2DTR	Recognized by the input deck parser and simulator support is available in the experimental "ebos" simulator
12	ROCKWNOD	Recognized by the input deck parser and simulator support is available in the experimental "ebos" simulator.
13	SGLPC	SGLPC defines the connate gas saturation for all the cells in the model via an array when the end-point scaling option has been invoked. Recognized by the input deck parser, and internalised into OPM Flow's 3D property representations. Missing some functionality. Use with caution.
14	STONE	This keyword is an alias for STONE2 keyword that activates Stone's second three phase oil relative permeability model as modified by Aziz and Settai. Keyword was previously supported by OPM Flow but not recognized by the input deck parser. This has now been fixed and the keyword is fully functional as per the documentation in the manual.
15	STONE2	This keyword activates Stone's second three phase oil relative permeability model as modified by Aziz and Settar. Keyword was previously supported by OPM Flow but not recognized by the input deck parser. This has now been fixed and the keyword is fully functional as per the documentation in the manual.
16	SWLPC	SWLPC defines the connate water saturation for all the cells in the model via an array when the end-point scaling option has been invoked. Recognized by the input deck parser, and internalised into OPM Flow's 3D property representations. Missing some functionality. Use with caution.
17	TBLK	Recognized by the input deck parser and simulator support is available in the experimental "ebos" simulator
18	THPRESFT	Recognized by the input deck parser and simulator support is available in the experimental "ebos" simulator.
19	WLIST	WLIST declares a group of wells to belong to a named well list.

Notes:

1) Cells colored in green in the "No." column indicate that the keyword is recognized by the input deck parser and fully or partially supported by OPM Flow.

2) Cells colored in orange in the "No." column indicate that the keyword is recognized by the input deck parser but not supported by OPM Flow.

3) Cells colored in red in the "No." column indicate that the keyword is not recognized by the input deck parser and OPM Flow.

Table B.13: New Keywords for the 2019-04 Release

Bård Skaflestad, Tor Harald Sandve, and David Baxendale.

B.10 Release 2018-10

The Open Porous Media project is please to announce that version 2018.10 of the OPM suite of simulation software has been released. Binary packages for Red-Hat Enterprise Linux 6 and 7 and Ubuntu 16.04 and 18.04 are available for download at the OPM website download page *https://opm-project.org/?page_id=36.* Installation instructions can also be found at the download page as well as in section *CHAPTER 2: INSTALLING AND RUNNING FLOW* of this manual.

In addition to the usual list of fixes and improvements two significant improvements include:

1) OPM Flow can now write restart files which can be used to restart runs using the commercial simulator.

2) Performance has been improved significantly, on selected field models, where OPM Flow is significantly faster than the commercial simulator.

Due to problems with the Zoltan package we have unfortunately been forced to disable MPI for the Ubuntu 18.04 package. We are looking into this, and if possible we will make updated packages at a later stage.

In terms of new features OPM Flow now includes an option for thermal modeling. The energy black-oil implementation in OPM Flow is a mixture of the commercial simulators black-oil and the commercial simulators "compositional thermal" keywords, as well as some OPM Flow specific keywords. The temperature option (TEMP keyword) and the thermal option (THERMAL keyword) are two separate modeling facilities in the commercial simulator. OPM Flow's thermal implementation is based on solving the energy equation fully coupled with the black-oil equations so the results are not directly equivalent to commercial simulator's black-oil TEMP or compositional THERMAL formulations. See the *5.3.140 THERMAL– Activate the Thermal Modeling Option* keyword in the RUNSPEC section outlining the available keywords.

Apart form the new thermal keywords summarized in section *5.3.140 THERMAL– Activate the Thermal Modeling Option*, the following new keywords have been incorporated in this release and are active:

No.	Keyword	Comment
1	GDFILE	The GDFILE keyword loads a GRID file that contains the structural data for the grid as a set of topological cuboidal cells, and EGRID files that contain structural and property data. Fully functional – Not Working in this Release
2	PLMIXNUM	The PLMIXNUM keyword defines the polymer region number for each grid block that is used to assign the mixing tables as well as the maximum polymer and salt concentrations, for when the polymer option has been activated.
3	TOLCRIT	This keyword defines the Critical Saturation Tolerance.
4	ISGLPC	The WSEGSICD keyword defines a multi-segment well segment to be a spiral Inflow Control Device. ("ICD") as part of a completion for a multi-segment well.

Notes:

1) Cells colored in green in the "No." column indicate that the keyword is recognized by the input deck parser and fully or partially supported by OPM Flow.

2) Cells colored in orange in the "No." column indicate that the keyword is recognized by the input deck parser but not supported by OPM Flow.

3) Cells colored in red in the "No." column indicate that the keyword is not recognized by the input deck parser and OPM Flow.

Table B.14: New Keywords for the 2018-10 Release

Joakim Hove

B.11 RELEASE 2018-04

The Open Porous Media project is please to announce that version 2018.04 of the OPM suite of simulation software has been release. Installation instructions can found on OPM website download page *https://opm-project.org/?page_id=36* and in section *CHAPTER 2: INSTALLING AND RUNNING FLOW* of this manual. Packages for Ubuntu 16.04 and Red-Hat Enterprise Linux 6 and 7 is prepared. New in this release is that also the Red-Hat packages are shipped with mpi support.

In addition to various minor bug-fixes and a reorganization of the code, the release contains new functionality for the OPM Flow simulator like DRSDT support, experimental CPR preconditioning and enhanced output capability. Note that number of modules are reduced to simplify the build process and the code maintenance. The new module organization is shown opposite.

Since the 2017.10 release the opm-core module has been removed, and the modules opm-parser and opm-output have been folded into opm-common.

Figure B.4: Module Structure for 2018-04 Release
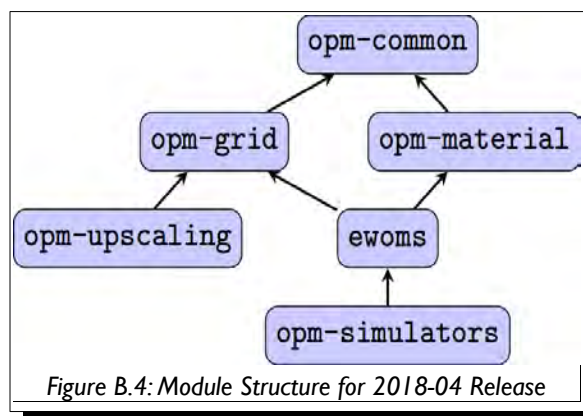
In terms of new features OPM Flow now includes analytical aquifers using the Carter-Tracy analytical aquifer and the ability model multi-segment wells. The following new keywords have been incorporated in this release and are active:

No.	Keyword	Comment
1	AQUANCON	AQUANCON keyword defines how analytical aquifers are connected to the simulation grid., this includes Carter-Tracy and Fetkovich analytical aquifers.
2	AQUCT	The AQUCT keyword defines Carter-Tracy aquifers, the properties of the aquifer, including the Carter-Tracy aquifer influence function associated with the aquifer.
3	AQUDIMS	The AQUDIMS keyword defines the dimensions of the various aquifer property data.
4	AQUTAB	AQUTAB keyword defines additional Carter-Tracy aquifer functions to be used in the model.
5	COMSEGS	The COMSEGS keyword defines how a multi-segment well is connected to the reservoir by defining or modifying existing well connections..
6	DRSDT	DRSDT defines the maximum rate at which the solution gas-oil ratio (Rs) can be increased in a grid cell.
7	DRVDT	DRVDT defines the maximum rate at which the solution oil-gas ratio or condensate-gas ratio (Rv) can be increased in a grid cell.
8	WELSEGS	The WELSEGS keyword defines a well to be a multi-segment well and defines the well's segment structure.
9	WSEGSDIMS	The WSEGSDIMS keyword defines the multi-segment well dimensions for the multi-segment well model.

No.	Keyword	Comment
Notes:		

    1)   Cells colored in green in the "No." column indicate that the keyword is recognized by the input deck parser and fully or partially supported by OPM Flow.

    2)   Cells colored in orange in the "No." column indicate that the keyword is recognized by the input deck parser but not supported by OPM Flow.

    3)   Cells colored in red in the "No." column indicate that the keyword is not recognized by the input deck parser and OPM Flow.

Table B.15: New Keywords for the 2018-04 Release

Tor Harald Sandve

B.12 Release 2017-10 Update 1

We have created an update for the 2017.10 release. It fixes a few bugs in Flow that could affect simulation results slightly and also lead to very bad performance when running Flow in parallel using MPI. The effect was most pronounced when running with more than 4 MPI processes.

Binary packages for Ubuntu 16.04 and Red Hat Enterprise Linux 6 and 7 have been updated, and for most users your systems will ask to install the updated version or do it automatically.

For those who compile OPM from source, the release branches on GitHub have been updated and tagged with

```
release/2017.10/update1
```

The master branch of course includes the same fixes.

Atgeirr Flø Rasmussen

B.13 Release 2017-10

On behalf of the OPM project, I'm happy to announce that version 2017.10 has been released. Packages for Ubuntu 16.04 and Red-Hat Enterprise Linux 6 and 7 have been prepared or should be available soon.

As usual, this release contains a multitude of new features and improvements. Most notable are probably that the Flow simulator is now considerably faster than in the 2017.04 release, Flow now supports the solvent and polymer black-oil extensions and that there now is freely available documentation for the file format that is used to specify the input.

Finally, as the release manager, I'd take the opportunity and thank everyone involved in making the release process for 2017.10 go as smoothly as it did.

Andreas Lauser

B.14 Release 2017-04

The Open Porous Media project is glad to announce that version 2017.04 of the OPM suite of simulation software has been released! Installation instructions can found on our download page.

Certainly the most significant change of this release is the introduction of the "flow_ebos" simulator. Compared to the previous "flow" simulators, "flow_ebos" uses a different approach to linearize the non-linear system of partial differential equations and as a result exhibits significantly better performance. The new simulator is intended to eventually fully replace the current family of "flow" simulators (i.e., "flow", "flow_mpi", "flow_solvent", "flow_polymer", etc.) and should already provide a proper superset of the capabilities of the "flow" simulator of previous OPM releases. For this reason, the name "flow" has been made an alias for "flow_ebos" in OPM 2017.04. If, for some reason, the previous "flow" simulator must be used, it is still shipped under the name "flow_legacy", but we strongly encourage you to send us bug reports if you encounter any case that can be simulated using "flow_legacy" but not using "flow_ebos".

Besides the introduction of "flow_ebos", plenty unit tests have been added, a plethora of bugs has been fixed, well handling has been considerably improved and now supports e.g. top-hole pressure controls and vertical flow performance tables, ECL output and restart capabilities have been made much more comprehensive, and all grid related functionality of opm-core has been moved to the opm-grid module in preparation of the former module's eventual retirement. In addition, a Docker container has been uploaded to Docker Hub to ease deployment for people who are into container technologies.

Last but not least, I would like to thank everyone who contributed to making the many changes of this release happen so smoothly.

Modules involved in the release (maintainers are given in parenthesis):

- opm-data (Alf Birger Rustad)

- opm-common (Atgeirr Rasmussen, Bård Skaflestad, Arne Morten Kvarving, Joakim Hove, Robert Klöfkorn, Tor Harald Sandve, and Andreas Lauser)

- opm-parser (Joakim Hove)

- opm-output (Joakim Hove)

- opm-grid (Atgeirr Rasmussen, Robert Klöfkorn, and Bård Skaflestad)

- opm-material (Andreas Lauser, Robert Klöfkorn, and Tor Harald Sandve)

- opm-core (Atgeirr Rasmussen, Robert Klöfkorn, and Bård Skaflestad)

- ewoms (Andreas Lauser, Robert Klöfkorn, and Tor Harald Sandve)

- opm-simulators (Atgeirr Rasmussen, Robert Klöfkorn, Tor Harald Sandve, and Andreas Lauser)

- opm-upscaling (Arne Morten Kvarving, Atgeirr Rasmussen, and Bård Skaflestad)

Andreas Lauser