



Permeability of the Montney Formation in the Western Canada Sedimentary Basin: Insights from Different Laboratory Measurements

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Summary

Permeability is a critical parameter for evaluating unconventional shale or tight gas and oil reservoirs such as the Montney Formation in the Western Canada Sedimentary Basin. Permeability is also one of the most difficult parameters to be accurately and consistently determined in the laboratory and field as it is a two-dimensional tensor and is dependent on many factors (e.g., test methods, sampling or testing scales, heterogeneities in fabrics, pore networks and pore-throat size distribution, transport mechanisms, pore pressure and confining stress). Although laboratory permeability measurement is limited to samples on the scale of centimeters or less, it provides valuable insights on hydrocarbon transmissibility of the reservoir matrix rock. Several methods have been developed for permeability measurements of unconventional reservoirs but each method has limitations and specific applications and often yields different permeability values even for the same sample.

In this study, various permeability measurements on samples from 46 Montney wells in Alberta and British Columbia are examined. The permeability data set has primarily been obtained using transient pressure fall-off and pressure pulse-decay methods due to the relatively low permeability seen throughout the Montney Formation. A unique data set of permeability determined from canister desorption tests is also analyzed and compared to other permeability measurements. Direct permeability measurements obtained using different techniques are further compared with permeability values predicted using models based on mercury intrusion capillary pressure (MICP) data. The results show that the pressure fall-off (kpf) or GRI (kgri) permeability to helium correlates strongly with porosity. The kpf of crushed samples (20/35 meshes) ranges from $<5e-6$ md to $>1e-3$ md with porosity increasing from 3% to 13%. The pressure fall-off permeability (kpf) of plug samples is about two orders of magnitude higher than kpf of crushed samples. Pressure pulse-decay permeability (kpdp) under initial in-situ effective confining stress conditions is generally higher than the pressure fall-off permeability of crushed samples but lower than that of core plugs. Pressure pulse-decay permeability (kpdp) of visually intact samples varies over two orders of magnitude for a given porosity, which is likely a result of variable sample characteristics (e.g., with or without micro fractures, net confining stresses applied due to different sample depths and regional locations, mineralogy, amount and type of organic matter, and porosity and pore-throat size). The pulse-decay permeability of fractured samples varies widely over 3 orders of magnitude and is up to 3 orders of magnitude higher than kpdp of intact samples, indicating favorable enhancement of permeability by unproped fractures in the Montney Formation. Out of eight MICP-based permeability models tested in this study, the Winland model (Kolodzie, 1980) and the modified Winland model by Di and Jensen (2015) predict the most comparable permeability to the pulse-decay permeability measured on intact samples. The permeability from these models has stronger correlations with pressure fall-off permeability measured on both intact and fractured core plugs than the other models. For the Montney Formation, the strong

dependence of gas permeability on pore pressure and confining stress is also highlighted. The pore pressure and stress dependence of permeability is characterized by a modified Klinkenberg effects correction equation. Liquid permeability to decane or oil is about one order of magnitude lower than gas permeability under similar confining stresses. Variable permeability from different methods even on the same Montney samples underlines the limitations and specific applications of each method, and implies the strong heterogeneities in mineralogical fabrics, organic matter distribution and pore size distributions of the Montney samples. The implications of different laboratory methods for formation evaluation are further discussed, and a practical fit-for purpose approach is recommended for the measurement of permeability, which allows for a more rigorous evaluation of in-situ matrix permeability of the Montney Formation and other unconventional shale and tight reservoirs.