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Hazard assessment of hydraulic fracturing chemicals using an indexing method

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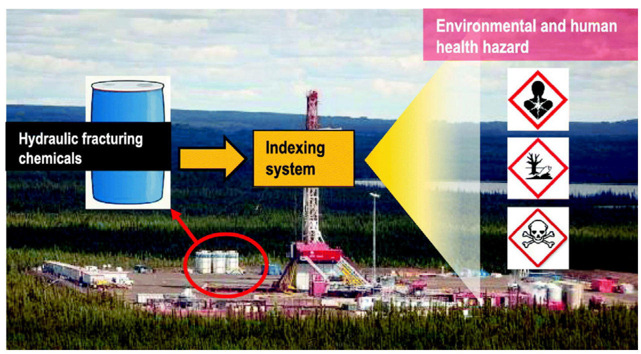
HIGHLIGHTS

- Assessed hydraulic fracturing chemicals using an indexing method
- Identified iron control agents as the most critical additive category
- Identified hydraulic fracturing additives as medium-level hazards overall
- Identified friction reducers as the category of lowest data completeness
- Aquatic toxicity and carcinogenicity are the main hazards of ingredients.

GRAPHICAL ABSTRACT



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ABSTRACT

The rapid expansion of unconventional natural gas production has triggered considerable public concerns, particularly regarding environmental and human health (EHH) risks posed by various chemical additives used in hydraulic fracturing (HF) operations. There is a need to assess the potential EHH hazards of additives used in real-world HF operations. In this study, HF additive and fracturing fluid data was acquired, and EHH hazards were assessed using an indexing approach. The indexing system analyzed chemical toxicological data of different ingredients contained within additives and produced an aggregated EHH safety index for each additive, along with an indicator describing the completeness of the chemical toxicological data. The results show that commonly used additives are generally associated with medium-level EHH hazards. In each additive category, ingredients of high EHH concern were identified, and the high hazard designation was primarily attributed to ingredients' high aquatic toxicity and carcinogenic effects. Among all assessed additive categories, iron control agents were identified as the greatest EHH hazards. Lack of information, such as undisclosed ingredients and chemical toxicological data gaps, has resulted in different levels of assessment uncertainties. In particular, friction reducers show the highest data incompleteness with regards to EHH hazards. This study reveals the potential EHH hazards associated with chemicals used in current HF field operations and can provide decision makers with valuable information to facilitate sustainable and responsible unconventional gas production.

1. Introduction

Unconventional natural gas production has significantly expanded in North America, owing to combined use of horizontal drilling and hydraulic fracturing (HF) techniques. These technical advances have

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enabled exploitation of unconventional natural gas reservoirs, such as low-permeability organic-rich shale formations and "tight-gas" reservoirs, redrawing the domestic energy landscape in Canada (Rivard et al., 2014). In 2012, Canada was the third largest producer of natural gas in the world and exported $15.6 billion worth of natural gas. The unconventional gas industry was responsible for about 15% of total natural gas production. By 2025, Canadian natural gas production is projected to be at least 25% greater than current levels, and the increase will be primarily attributed to unconventional natural gas production (NEB, 2013).

In Canada, unconventional natural gas production has been distributed within several major shale plays, the most important plays include the Muskwa-Otter Park shale members of the Horn River Basin of Northern British Columbia (BC) and the adjacent Montney Basin, spanning the BC and Alberta border, as well as the Duvernay Formation in West-central Alberta (NRC, 2016). As a major natural gas producing province, BC is particularly well poised to benefit from the recent overhaul of the natural gas industry. As of 2014, over a thousand wells have been drilled for shale gas exploration or production in BC, and in most cases, completion processes have involved HF (FracFocus, 2014). The HF process involves the pumping of large volumes of fracturing fluid, consisting of a base fluid (primarily water), proppants (typically quartz sand), and various additives, under high pressure into a perforated wellbore to initiate and expand fractures within the adjacent geological formation (Vidic et al., 2013). The fractures increase the permeability of the formations, allowing for the previously trapped natural gas to flow through the formations into the wellbore (Ferrer and Thurman, 2015).

Despite the promising resource potentials and economic benefits, unconventional gas production has aroused considerable public concerns regarding environmental and human health (EHH) impacts caused by HF operations (Vengosh et al., 2014). The chemicals used in HF are of concern due to the potential of soil, groundwater, and surface water contamination (Boudet et al., 2014; Burton et al., 2016; Long, 2014; Vengosh et al., 2014). In HF, various additives are used in the fracturing fluids to meet different engineering requirements. The additives serve various functions, such as inhibiting the growth of microorganisms, facilitating the transportation of proppants into fractures, and preventing mineral scaling of the well (Stringfellow et al., 2014). An additive consists of several ingredients at different concentrations. The relationship between ingredients, additives, and fracturing fluids is outlined in Fig. 1. According to their functions, additives can be divided into several categories, including: gelling agents, friction reducers, crosslinkers, breakers, biocides, corrosion inhibitors, scale inhibitors, iron control chemicals, clay stabilizers, surfactants, and demulsifiers (Barati and Liang, 2014; Hurley et al., 2016; Stringfellow et al., 2014).

It has been reported that over 2500 additives, consisting of 750 different ingredients, have been used in HF operations in the United States (Soeder et al., 2014). A typical HF operation may use 3 to 12 additives based on the identified needs for the given well (Hurley et al., 2016). Some of these additives contain ingredients that are potential carcinogens, mutagens, reproductive toxicants, and substances with acute and long-term aquatic toxicities (Finkel and Hays, 2013; Kassotis et al., 2014; Rogers et al., 2015; Soeder et al., 2014; Stringfellow et al., 2014). Although there are various government regulations, industry codes-of-practice, and company standard operating procedures in place to prevent or minimize the likelihood of accidental releases of HF fluids, the risk of HF fluid contamination cannot be neglected. Any unintended release or disposal of the fluids could pose a health risk to the aquatic environment and the surrounding water users (Akob et al., 2016; Cozzarelli et al., 2017; Kassotis et al., 2016; Luek and Gonsior, 2017; Orem et al., 2017; Soeder et al., 2014). Additionally, since fracturing fluids usually contain a set of additives consisting of one or more ingredients, the composite hazard of additives is difficult to calculate, increasing the complexity and uncertainty in risk assessment.

The use of additives with minimized EHH effects is encouraged for the responsible and sustainable development of the unconventional gas industry (Gordalla et al., 2013; Hurley et al., 2016; Kargbo et al., 2010). Nevertheless, the process of selecting environmentally friendly additives can be difficult without knowing the respective EHH implications. Methods which can effectively assess the additive hazard and produce comparable results are therefore required to facilitate decision making. Various methods have been developed for evaluating potential EHH risks of chemicals used in the oil and gas industry (Hepburn, 2012; Hurley et al., 2016; Jordan et al., 2010; Verslycke et al., 2014), but limited results have been published reflecting the HF chemical hazards in a

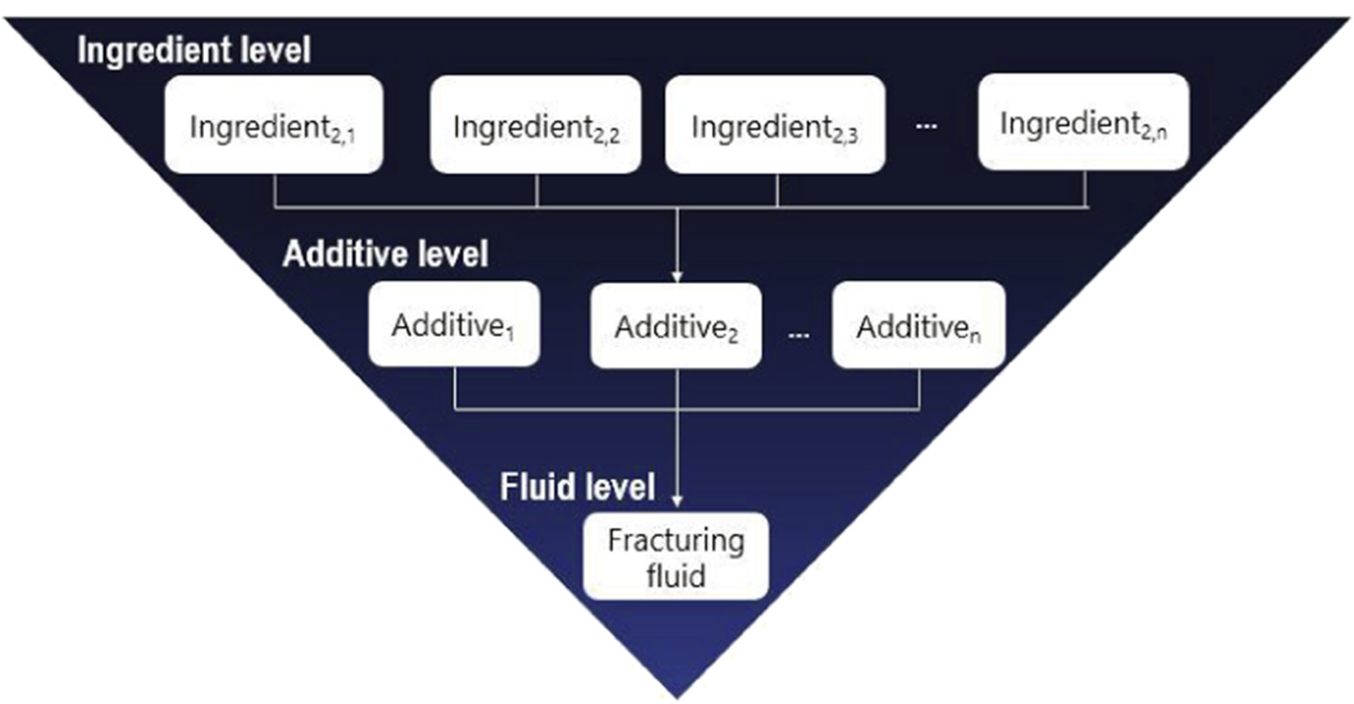

Fig. 1. Hydraulic fracturing chemical hierarchy.