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# Application of Water in Hydrothermal Conditions for Upgrading Heavy Oils: A Review

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**ABSTRACT:** The use of water in hydrothermal and supercritical conditions as a medium to upgrade heavy oil fractions has shown promising results and presents an interesting alternative for heavy oil processing. Water at these conditions improves transport properties increasing the solubility in the medium and reducing the viscosity of the oil, which facilitates the upgrading process. This review focuses on the use of water as a medium to recover and upgrade heavy oils. An analysis of the main reactions occurring, effect of process conditions, and role of water in the reaction mechanism is carried out based on experimental results found in the literature. Studies performed with model compounds that have enabled a proper understanding of the reaction mechanisms, kinetics, and effect of process conditions in the upgrading of heavy oil in near critical or supercritical water are included. An overview of the main challenges of the technology such as corrosion and salt deposition as well as some innovative reactor designs to solve them is provided. Information regarding research carried out in this field has been linked to the growing industrial interest in the technology showing recent developments and registration of patents on reactor designs and processes involving heavy oil upgrading in near and supercritical water.

## 1. INTRODUCTION

World energy consumption has increased significantly during the last few decades and is expected to increase 54% between the years 2010 and 2040.[1] Although the share of liquid fuels (mainly petroleum derived) in the energy market is expected to drop, they will continue to supply the majority of the energy consumed worldwide as shown in Figure 1. This fact, combined with the gradual decline in light oil production, has made heavy oil production and upgrading increasingly important in the global oil market. It is expected that heavy oil production will increase from 9.7 million barrels per day (mbpd) in 2010 to approximately 13 mbpd in 2035,[2] having received a boost from rising oil prices between 2005−2014 and the improvement of extraction and upgrading technologies that enable heavy oil processing.[3,4]

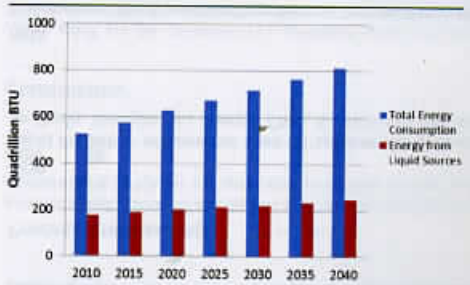


Figure 1. World energy consumption and energy supplied from liquid sources outlook 2010−2040. Adapted from ref 1.

**1.1. Heavy Oil.** There is not complete agreement on an accurate definition of heavy oil. Some authors define heavy oil as feedstocks with an API gravity below 20° and viscosities over 100 cP at reservoir conditions.[5,6] Heavy oil can also be defined as a feedstock with an API gravity below 22° and as an extra heavy oil if it has less than 10° API but a viscosity below 10,000 cP at reservoir conditions.[2] Feedstocks with a low API gravity and viscosities over 10,000 cP are considered natural bitumen.[2,5] Heavy oils are difficult to process because of their composition, which shows high heteroatom, asphaltene, and metal content as exemplified in Table 1.[7−11] These feeds cause common processing problems such as low yields to light fractions and catalyst deactivation, mainly due to metal deposits and coke formation.[12] Because of the nature of these oils, the most suitable refining processes seem to be those based on increasing the hydrogen to carbon ratio of the feedstock. This is achieved mainly with technologies based on hydrogen addition and carbon rejection processes. These technologies present advantages and disadvantages based on technical or economic grounds and are determined by the yields of upgraded oil achieved and its quality. Thermal cracking-based technologies can be generally applied to most feedstocks regardless of composition but result in low yields to light fractions and high coke production. On the contrary, hydrogen addition technologies produce high yields of light fractions but require great initial investments and high hydrogen consumption.[13,14] Nowadays, traditional oil refining technologies such as coking or hydrogenation are not suitable as a standalone refining method. For greater yields and an increased quality of oils to be obtained, combination and integration of process technologies to combine the main advantages of each technology in a single process is the best alternative.[14] Moreover, other technological

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