may contribute to molecular bromine formation during the neutralization of hydrobromic acid, incomplete HBr conversion due to the use of a solid bromide salt may in turn result in a significant loss of bromine from the system (in the water phase). Provided an excess of air was used, the bromide salt might eventually be converted to the oxide form, stopping any further loss of HBr in the water discard.

To separate water from bromine, a process may utilize condensation and phase separation to produce semi-dry liquid bromine and a water/bromine mixture. Other means for separating water from bromine, such as using an inert gas to strip the bromine from the water phase or using adsorption-based methods have also been proposed; however, such methods are minimally effective and result in a significant overall loss of halogen.

An oxychlorination process may first remove the water from HCl (a costly step) and then reacts the HCl with oxygen and hydrocarbon directly. Oxychlorination processes rely on the separation of HCl from the unreacted alkanes and higher hydrocarbon products by using water absorption, and subsequent recovery of anhydrous HCl from the aqueous hydrochloric acid. Processes for the absorption of HCl in water may dissapate the heat of absorption by contacting the HCl gas with ambient air, and also by the vaporization of water. Such processes may produce aqueous hydrochloric acid with a concentration of at least 35.5 wt %. Other processes may allow for the recovery of anhydrous HCl gas by extractive distillation using a chloride salt. Still other processes allow for the production of gaseous HCl from dilute aqueous HCl using an amine together with an inert water-immiscible solvent.

Although researchers have made some progress in the search for more efficient CH bond activation pathways for converting natural gas and other hydrocarbon feedstocks into fuels and other products, there remains a tremendous need for a continuous, economically viable, and more efficient process.

SUMMARY

This ~~invention~~disclosure generally relates to carbon-carbon coupling and, more particularly, to methods for converting hydrocarbon feedstocks into useful products.

An embodiment comprises a method comprising: providing a first halogen stream; providing a first alkane stream; reacting at least a portion of the first halogen stream with at least a portion of the first alkane stream in a first reaction vessel to form a first halogenated stream; providing a second alkane stream comprising C_2 and higher hydrocarbons; providing a second halogen stream; and reacting at least a portion of the second halogen stream with at least a portion of the second alkane stream in a second reaction vessel to form a second halogenated stream.

Another embodiment comprises a method comprising: providing a halogen stream; providing a first alkane stream; reacting at least a portion of the halogen stream with at least a portion of the first alkane stream to form a halogenated stream, wherein the halogenated stream comprises alkyl monohalides, alkyl polyhalides, and hydrogen halide; and contacting at least some of the alkyl monohalides with a coupling catalyst to form a product stream that comprises higher hydrocarbons and hydrogen halide.

In an aspect, there is provided a method comprising: providing a halogen stream; providing a first alkane stream; reacting at least a portion of the halogen stream with at least a portion of the first alkane stream to form a halogenated stream, wherein the halogenated stream comprises alkyl monohalides, alkyl polyhalides, and a hydrogen halide; providing a second alkane stream; and reacting at least a portion of the second alkane stream with at least a portion of the alkyl polyhalides to create at least some additional alkyl monohalides.

In another aspect, there is provided a method comprising: providing an alkyl halide stream comprising alkyl monohalides, alkyl polyhalides, and a hydrogen halide; providing a first alkane stream; reacting at least a portion of the first alkane stream with at least a portion of the alkyl halide stream to create at least some additional alkyl monohalides; contacting at least some of the alkyl monohalides and at least some of the additional alkyl monohalides with a catalyst to form a product stream that comprises higher hydrocarbons, hydrogen halide, and any unreacted portion of the first alkane stream; separating the unreacted portion of the first alkane stream from the product stream; providing a halogen stream; and reacting at least some of the unreacted portion of the first alkane stream separated from the product stream with the halogen to form the alkyl halide stream.

Still another embodiment comprises ~~A~~a method comprising: providing an alkyl halide stream; contacting at least some of the alkyl halides with a coupling catalyst to form a product stream comprising higher hydrocarbons and hydrogen halide; contacting the product stream with an aqueous solution comprising a metal halide to remove at least a portion of the hydrogen halide from the product stream; separating at least some of the metal halide from the aqueous solution; and heating the separated metal halide to generate a corresponding halogen.

An embodiment comprises a method comprising: providing an alkyl halide stream; contacting at least some of the alkyl halides with a coupling catalyst to form a product stream comprising higher hydrocarbons and hydrogen halide; contacting the product stream with a solid reactant to remove at least a portion of the hydrogen halide from the product stream; and reacting the solid reactant with a source of oxygen to generate a corresponding halogen.

Another embodiment comprises a method comprising: providing an alkyl halide stream; contacting at least some of the alkyl halides with a coupling catalyst to form a product stream comprising higher hydrocarbons and hydrogen halide; separating at least some of the product stream from the hydrogen halide; and contacting the hydrogen halide with oxygen and an aqueous solution comprising a metal capable of forming multiple stable oxidation states to generate a corresponding halogen and water.

Still another embodiment comprises a system comprising: a coupling reactor comprising a coupling catalyst for receiving an alkyl halide stream and contacting at least a portion of the alkyl halide stream with the coupling catalyst to form a product stream comprising higher hydrocarbons and hydrogen halide; a separator unit for separating at least some of the product stream from the hydrogen halide; and an oxidation reactor comprising an aqueous solution comprising a metal capable of forming multiple stable oxidation states for receiving a source of oxygen and at least a portion of the hydrogen halide from the separator unit and generating a corresponding halogen and water..

An embodiment comprises a method comprising: providing a halogen stream; providing an alkane stream; providing a decoking agent; and reacting at least a portion of the halogen stream with at least a portion of the alkane stream in the presence of a halogenation catalyst and the decoking agent to form a halogenated stream.

Another embodiment comprises a method comprising: providing a gas phase stream comprising an elemental halide; contacting the gas phase stream with a chilled brine in the liquid phase, wherein the chilled brine comprises an aqueous solution and a salt; separating the elemental halogen along with the chilled brine from the remainder of the gas phase stream that remains in the gas phase; and separating the elemental halide from the chilled brine.

Still another embodiment comprises a method comprising: providing an alkyl halide stream; contacting at least some of the alkyl halides with a coupling catalyst to form a product stream comprising higher hydrocarbons and hydrogen halide; separating the hydrogen halide from the product stream; and reacting the hydrogen halide with a source of oxygen in the presence of an oxidation catalyst to generate a corresponding halogen.

The features and advantages of the present ~~invention~~disclosure will be apparent to those skilled in the art. While numerous changes may be made by those skilled in the art, such changes are within the spirit of the ~~invention~~present disclosure.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic view of one embodiment of a continuous process for converting methane or natural gas into hydrocarbon chemicals according to the invention;

FIG. 2 is a schematic view of one embodiment of a continuous process for converting methane or natural gas into hydrocarbon fuels according to the invention;

FIG. 3 is a schematic view of one embodiment of a continuous process for converting methane or natural gas into hydrocarbon fuels according to the invention;

FIG. 4 is a schematic view of a subprocess for reproportionating polyhalides according to an alternate embodiment of the invention;

FIG. 5 is a schematic view of one embodiment of a continuous process for a halogenation reactor;

FIG. 6 is a schematic view of one embodiment of a monobromide separation column, for use in the practice of the invention;

FIG. 7 is a schematic view of one embodiment of a catalytic coupling reactor with multiple catalytic beds;

FIG. 8 is another schematic view of one embodiment of a catalytic coupling reactor with multiple catalytic beds;

FIG. 9 is a schematic view of one embodiment of an extractive distillation system, for use in the practice of the invention;

FIG. 10 is a schematic view of one embodiment of a temperature swing absorption system, for use in the practice of the invention;