MULTIPHASE HEAT TRANSFER DURING HYDRATE COMBUSTION
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Methane hydrates (clathrates), which occur naturally and abundantly in the permafrost and in deep ocean sediments, are ice-like structures caging guest methane molecules at a molar ratio of approximately 5.75:1 water/methane. In order to determine the energy release and the combustion characteristics of these hydrates, experimental and theoretical studies were performed. A simple energy balance of hydrate combustion with no energy loss shows that the energy release from the methane/air reaction (~ 890 kJ/mol-Hydrate) is sufficient to both melt (~ 35 kJ/mol-Hydrate) and evaporate (~ 235 kJ/mol-Hydrate) the water, with more than 70% of the thermal energy still available. However the high water vapor content acts as a heat sink, depressing the adiabatic flame temperature substantially. Results from related water-laden methane/air flame experiments and computations suggest that steady combustion requires flame temperatures that correspond to water content less than half the total in the hydrate. This finding is significant, as it shows that continuous hydrate combustion requires that some liquid water drain away and not be evaporated into the flame zone. The poster shows images of hydrate flames that demonstrate this draining behavior. Based on measurements from the hydrate burns, a simple one-dimensional three-layer physical model was developed to characterize the heat transfer dominated process. Layer 1 is a semi-infinite hydrate cake, layer 2 is a thin water film, and layer 3 is the gas phase region between the heat source (flame) and the film surface. We then compute the heat flux needed from the heat source to conduct through the liquid water and dissociate the hydrate at a sufficient rate to sustain fuel flow to a flame. At steady conditions, the thickness of the water layer is controlled by the difference between the hydrate dissociation rate and the water evaporation rate into the gas phase.

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The combustion of nanofluid fuels has attracted great attentions recently and the fundamental understanding of the thermal properties of nanofluid fuels is needed. Although the enhanced thermal conductivity of nanofluids has been quite well studied, their radiative properties have rarely been investigated. The present paper quantitatively determined the radiative properties of various nanofluid fuels and their effects on droplet evaporation under Infrared (IR) radiation. The optical properties, including the transmission spectrum and extinction coefficients, of nanofluid fuels with stable suspension of metallic energetic particles and carbon-based nanostructures were experimentally determined. The optical properties were also modeled using Rayleigh approximation based on the radiation interaction with nanoparticles. The importance of radiation absorption and scattering was identified for various nanofluids.

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Numerical simulations have been performed to examine fuel conversion and oxygen permeation within an oxygen permeable inorganic membrane reactor (i.e., ion transport membrane (ITM) reactor). In the presence of a reactive gas such as methane on the sweep side of the ITM, fuel conversion takes place using a fuel diluent such as recirculated carbon dioxide (replacing nitrogen in air). The nature of oxygen permeation does not allow pre-mixing of fuel and oxidizer (i.e., sweep gas and permeated oxygen), establishing non-premixed flames. However, the oxygen permeation rate in the ITM reactor is not a control parameter, rather than depends on the oxygen partial pressure and the membrane temperature that may change substantially due to the chemical reactions. Thus, hydrocarbon conversion and product selectivity are highly interconnected with the oxygen permeation rate through local flow conditions. The transport of reaction products and heat transfer from the reaction zone towards the membrane surface influences the permeation rate and the flame temperature. Furthermore, the amount of fuel converted and product selectivity change due to the flame front location relative to the membrane and the corresponding permeation rate. In addition, the high carbon dioxide concentration in the sweep gas (fuel) stream affects the methane oxidation kinetics and reaction products via its decomposition reactions. As a result, the radical concentration in the ITM reactor is significantly reduced, and the methane oxidation kinetics is delayed. A large fraction of carbon monoxide is produced, whereas the hydrogen production is lowered. The hydrocarbon pyrolysis is also influenced by the high concentration carbon dioxide on the sweep side of
the ITM. While ITM reactors hold considerable potential for reducing energetic penalties of gas separation, as well as improving product selectivity and yields, this work demonstrates the necessity of considering the interaction of the complex fuel conversion and oxygen permeation processes.

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W5P047: NUMERICAL STUDY OF CO AND CO₂ FORMATION IN H₂-CH₄ BLENDED FLAME UNDER MILD CONDITION
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Reduction of air pollutants formation from hydrocarbon combustion process needs improving of combustion systems. MILD combustion technique is an opportunity to catch such a goal. MILD combustion is a combustion regime which can be yield by high temperature preheating and high level dilution. In this paper, CO and CO₂ formation mechanisms for CH₄-H₂ blended fuel combustion are studied using CFD and also zero dimensional WSR analysis. The modeling is presented for the JHC burner of Dally which is designed to emulate a moderate and intense low oxygen dilution (MILD) combustion regime. The RANS equations with modified k-ε equations are solved in an axisymmetric 2-D computational domain. The DRM-22 reduced mechanism is considered to represent the chemical reactions. The effects of oxidizer oxygen concentration and fuel hydrogen content are studied on methane oxidation pathways. Results show that, under MILD condition, the higher hydrocarbon oxidation pathways are effective on CO and CO₂ formation. Ratio between the main route of methane oxidation and ethane route is the main reason of CO increment at higher O₂ level under MILD condition in JHC laboratory burner. The WSR analysis illustrates that a decrease of O₂ concentration in oxidizer does not always leads to lower production of CO and CO₂.

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W5P048: COMPUTATIONAL STUDY OF MILD COMBUSTION AND POLLUTANTS EMISSION CHARACTERISTICS IN A HEATED WALL-CONFINED JET
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The characteristics of MILD combustion and pollutants emission characteristics in a wall-confined CH₄-air coflow jet were investigated computationally with the ANSYS FLUENT 13.0. A modified standard k-ε turbulent model and EDC (Eddy Dissipation Concept-based) model, well known to be reasonable in predicting the combustion and flow field of jet and MILD combustor, were used in the computations of wall-confined jet. A 3-step global chemistry, including 6 species, CH₄, CO, CO₂, H₂O, O₂ and N₂, was adopted in the EDC calculation. Three-types of NO, such as thermal NO, prompt NO and NO via N₂O, were considered in the computation to investigate the NO emission. The DOM (Discrete Ordinate Method) and WSGGM (Weighted-Sum of Gray Gas Model) were incorporated to investigate the radiation effects from the MILD combustion field. The MILD combustion characteristics and CO and NO emission were investigated in the functions of dilution rate of combustion products and inflowing air stream temperature. The inflowing air stream was diluted with main combustion products, which consisted of CO, CO₂, H₂O, and N₂. The main combustion products of premixed CH₄-air of stoichiometry were determined using an unsteady PSR code. The dilution rate of combustion products in air stream was controlled from 0 to 70% by volume, and the temperature of inflowing air stream was fixed to 900 K, 1100 K and 1300 K.

In order to quantify the emissions of pollutants, emission indices of CO (EICO) and NO (EINO) were introduced. For a fixed air stream temperature, the maximum flame temperature gradually decreased and temperature distribution of jet became nearly uniform (MILD combustion state) except fuel nozzle exit as dilution rate increased. In addition, as the dilution rate increased for each air stream temperature, EINO sharply decreased and EICO also decreased gradually. It was found that the EICO had a negative value for large dilution rates. This interesting result means that MILD combustion has advantages in low-CO emission as well as is very effect in the consumption of additionally supplied CO. The CO consumption mechanism in MILD combustion was also confirmed by OPPDIF with a detailed chemistry. Thus, it is necessary that the CO consumption mechanism in MILD combustion should be investigated thoroughly in future works.

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