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**Objective:** An energy recovery system consisting of an efficient SMR and/or methane autothermal reforming process. Further the end product of this system will be hydrogen gas.

**Scope:** Provide pre-engineering guidance for procurement of an appropriate catalyzed reformer capable of using our energy flows at the lowest appropriate temperature. Included will be an analysis regarding technical feasibility. Following the feasibility study, produce a pre-engineered concept of the reformer. Out of the study the optimal reaction pressure and temperature conditions, and recommendation for a low temperature catalytic system will materialize.

**Available compounds (reactants) available for reforming:**

**Saturated Steam (H2O):**  Up to 36 kg/hr

 Temperature 125 deg. C

 Pressure 20 psig

 H vaporization / time 28 kw (with respect to saturated liquid at same

temperature and pressure)

**Methane:**  Up to 18 kg/hr

 Temperature 125 deg. C

 Pressure 20 psig

**High temperature air:**  7 cu.m / min.

 Temperature 638 deg. C

 Enthalpy/time 31 kw

**Assumptions to the project:**

1. High temperature air will provide for the enthalpy of the reaction and for preheating the reactants to SMR temperature.

2. Incoming reactant stream is assumed to be 1 part CH4 and 2 parts H2O (steam) under superheated condition

3. Off gas consisting methane will be:

1. Recycled through reactor with feed stock for additional hydrogen
2. Recycled through a combustion chamber for additional process energy released through complete combustion.

**Point 1** Steam

 Mass 36 kg/hr (est.)

 Pressure 20 psig

 Temp. Base 125 deg C

 Energy/ time 28 kw (saturated steam, referenced to enthalpy for

saturated liquid at 125 deg C)

**Point 2** Heated Air (for heat transfer with reaction bed):

 Mass / volume 7 cu.m/min

 Temp. 638 deg C

 Energy 31 kw

**Point 3** CH4 standard pipeline natural gas

 Mass estimated: Up to 18 kg/hr for (SMR + shift reaction)

Pressure To be determined

Temp. To be determined

Energy Negligible kw (most of the methane not being used for combustion)

**Point 4** Reformer

The reformer is anticipated to be of the SMR family of hydrogen reactors. It is not meant to restrict this project to this reformer if another method is known to be more efficient regarding the successful fruition of this project.

**Possible reactions to be considered:**

Steam reforming *CH4* + *H2 O*  *CO* + 3*H2* 206.2 (kJ/mole)

Water gas shift *CO* + *H2 O*  *CO 2* + *H2* -41.1(kJ/mole)

Overall Steam reforming *CH4* + 2*H2 O*  *CO2* + 4*H2* 164.9 (kJ/mole)

 **Point 5** Feed stock

 Mass Steam up to 36 kg/hr

 Methane up to 18 kg/hr

 Pressure 20 psig

 Temp. 125 deg C

**Point 6** Steam

 Mass Steam up to 36 kg/hr

 Methane up to 18 kg/hr

 Pressure 20 psig

 Temp. 500 deg C

HX 1 required heat transfer 13 kw to raise temp from 125 deg C to 500 deg C for methane and steam

**Point 7** Volumetric flow rateestimated 5.8 cu.m/min at 500 deg C:

 Mass

 Pressure > 1 atm

 Temp. 500 deg C

**Point 8** Energy Recoveries (for makeup water heat recovery):

 Volumetric flow rate 5.5 cu.m/ min at 125 deg C

 Pressure > 1 atm

 Temp. 125 deg C

**Point 9** Additional steam and CH4 will be added to the feed stock to compensate for any CH4 in the off gas stream that is used for combustion.

The product gas stream is expected to have the following composition (assuming the incoming reactant stream (Point 5) consists of 1 part of methane and 2 parts of H2O (molar ratio) as per the stoichiometric reaction for the combined SMR + shift reaction):

|  |  |
| --- | --- |
|  | Mole fraction |
| Reactant/ Product  | Input (point 5) | Output (point 10 a) |
| CH4 | 0.33 | 0.22 |
| H2O | 0.67 | 0.44 |
| CO | 0 | 0.01 |
| H2 | 0 | 0.27 |
| CO2 | 0 | 0.06 |

The equilibrium constants used were 1.93x10-3 at 773 K and 1 atm pressure for the SMR reaction and 3.83 at 773 K and 1 atm pressure for the Shift reaction.

Pressure 1 – 2 atm

 Temp. 500 deg C

**Point 9a** Air for off gas re-burn

 Volumetric flow rate Approx 31 Nm3/hr

 Pressure To be determined

 Temp. To be determined

**Point 9b** Methane for complete combustion (off-gas reburn) to provide for endothermic SMR

Flow Rate 2 kg/hr

 Pressure > 1 atm

 Temperature 500 deg C

Heat of combustion on complete oxidation of methane: 31 kW

**Point 10** (SMR +shift reaction) It is assumed that the product gas from the reaction will be purified to obtain pure hydrogen.

 Mass; Hydrogen (Assumed: 1 mole of methane and 2 moles of steam (point 5) results in approx 0.97 moles of hydrogen through SMR only)

 Pressure To be determined

 Temp. 500 deg C

**Point 10a**  Hydrogen separation process (to be determined)

 Mass

 Pressure

 Temp.