

## Hydrate Process Analysis Focusing on Energy Requirement

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### Abstract

Transporting gas in the form of a gas hydrate can prove to be very useful in the supply chain of natural gas to meet future energy demand. There are major challenges that exist in effectively capturing, storing, transporting and utilizing form of energy. The details of the work flow in this paper evaluates the entire hydrate process with particular focus on energy balance using hydrate technology to capture and transport five (5) MMscf/d from Trinidad to Jamaica. The overall energy requirement of the process which involves heating, cooling and expansion is in the range 14-20% of the energy of the gas transported in hydrate form.

**Key words:** Energy requirement; Hydrate; Gas hydrate

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### INTRODUCTION

Gas hydrate may be a useful means of capturing, storing and transporting stranded and associated gas. This work proposes a workflow for capturing, storing and transporting gas in the hydrate form, particularly

for Caribbean situations where there are infrastructural constraints such as lack of pipelines. The study analyzes the gas hydrate value chain for transportation of 5 MMscf/d of natural gas from Trinidad to Jamaica using a particular natural gas sample.

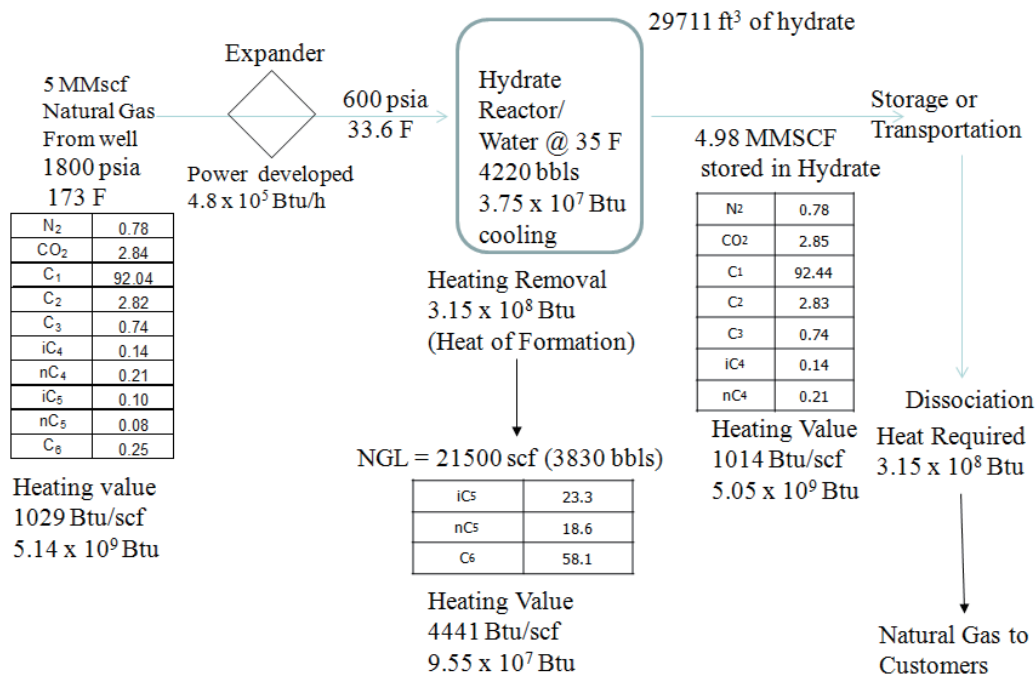
### ENERGY BALANCE FOR THE HYDRATE PROCESS

The hydrate process energy requirements are shown **Figure 1** for a particular natural gas sample producing 5MMscf/d. The heating value of the gas before and after hydrate formation is shown. This is particularly important since the gas is sold based on the heating value. Gas from the well is passed through an expander to lower the temperature and pressure suitable for hydrate formation.

The power developed by the expansion process is  $4.8 \times 10^5$  Btu/h. After the expansion the natural gas is pumped into the hydrate vessel with 4220 bbls of cold water. The cooling requirement for water is also shown in the figure. The formation of hydrate results in large amount of heat of formation that must be removed during the process.

The natural gas composition may have heavier components ( $C_5$  or higher), as in the case of this gas sample. In the hydrate formation process, only  $C_1$  to  $C_4$  are captured, and the higher components ( $C_5$  and higher) separate in the process as natural gas liquids (NGL). In this case 3830 bbls of NGL is separated out with a heating value of 4441 Btu/scf and is useful energy.

The same amount of energy removed during the formation of the hydrate is same energy requirement for dissociation.



**Figure 1**  
Hydrate process showing energy balance

**Heating Value**

The heating value of the gas sample is estimated to be 1029 Btu/scf and this is shown below in **Table 1** For 5 MMscf of gas, the heating value translates to 5.14 x 10<sup>9</sup> Btu.

**Table 1**  
Heating Value Estimation for a Gas Sample before Hydrate

		Mole fraction	Ideal heating value	Gas mix before hydrate
Sample	2		Btu/scf	Btu/scf
Nitrogen	N <sub>2</sub>	0.78	0.0	0.0
Carbon Dioxide	CO <sub>2</sub>	2.84	0.0	0.0
Methane	C <sub>1</sub>	92.04	1010.0	929.6
Ethane	C <sub>2</sub>	2.82	1769.7	49.9
Propane	C <sub>3</sub>	0.74	2516.1	18.6
Iso-butane	iC <sub>4</sub>	0.14	3251.9	4.6
N-Butane	nC <sub>4</sub>	0.21	3262.3	6.9
Iso-pentane	iC <sub>5</sub>	0.10	4000.9	4.0
N-Pentane	nC <sub>5</sub>	0.08	4008.9	3.2
Hexanes	C <sub>6</sub>	0.25	4755.9	11.9
Heptanes	C <sub>7</sub>	0.00	5502.5	0.0
Octanes	C <sub>8</sub>	0.00	6248.9	0.0
Nonanes	C <sub>9</sub>	0.00	6996.5	0.0
Decanes	C <sub>10</sub>	0.00	7742.9	0.0
Total		100		1028.6

**Table 2** shows the heating value of the gas stored in the hydrate is estimated at 1014 Btu/scf with 29711 ft<sup>3</sup> of hydrate being formed.

**Table 2**  
**Heating Value Estimation for a Gas Sample in Hydrate**

		Mole fraction	Ideal heating value	Gas mix in hydrate
Sample 2 in hydrate			Btu/scf	Btu/scf
Nitrogen	N2	0.78	0.0	0.0
Carbon Dioxide	CO2	2.85	0.0	0.0
Methane	C1	92.44	1010.0	933.6
Ethane	C2	2.83	1769.7	50.1
Propane	C3	0.74	2516.1	18.7
Iso-butane	iC4	0.14	3251.9	4.6
N-Butane	nC4	0.21	3262.3	6.9
Total		100		1013.9

The natural gas liquids may separate during the hydrate process for sample 2 and provides useful energy. The heating value of the NGL is estimated at 4441 Btu/scf. This is shown in **Table 3**.

**Table 3**  
**Heating Value Estimation for Natural Gas Liquid (NGL)**

		Mole fraction	Ideal heating value	Gas mix in hydrate
Sample 2 NGL			Btu/scf	Btu/scf
Iso-pentane	iC5	23.26	4000.9	930.4
N-Pentane	nC5	18.60	4008.9	745.8
Hexanes	C6	58.14	4755.9	2765.1
Heptanes	C7	0.00	5502.5	0.0
Octanes	C8	0.00	6248.9	0.0
Nonanes	C9	0.00	6996.5	0.0
Decanes	C10	0.00	7742.9	0.0
Total		100.00		4441.3

**Expansion**

The expansion process must also ensure the gas sample remains in the single phase region of the phase diagram, which is important in the design process. From the

wellhead, the gas flows through a turbo-expander, which causes the gas temperature to drop to 35 F, and the pressure to drop to 600 psia, assuming an efficiency of 85% or 90% depending on the sample.

**Table 4**  
**Horse Power Generated and Outlet Temperature for Various Expansion Efficiencies**

Efficiency	100%	95%	90%	85%	80%
Inlet, Enthalpy, Btu/lb-mol	574.7	574.7	574.7	574.7	574.7
Outlet, Enthalpy, Btu/lb-mol	-487.8	-434.6	-381.5	-328.4	-275.3
Change Enthalpy, Btu/lb-mol	1062.5	1009.3	956.2	903.1	850
HP, Btu/hr	584375	527359.25	473319	422199.3	374000
Outlet Pressure, psia	600	600	600	600	600
Outlet Temperature, F	19.4	25	30.3	35.5	41.3

The power developed by the expander and the outlet temperatures are shown in **Table 4**. The data in the table were obtained from the commercial simulator. An efficiency of at least 85% is required to obtain an outlet temperature of 35 F, required for hydrate formation. This generates  $1.01 \times 10^7$  Btu of energy. Below is a sample calculation of power from the expander:

$$Power = \Delta h \times w \times \eta_e$$

where:

$\Delta h$  = change in enthalpy, btu/lbmole,

$w$  = flow rate, lbmole/hr

$\eta_e$  = expander efficiency, %

For an 85% efficiency,  $\Delta h = 903.1$  btu/lbmole and  $w = 550$  lbmole/hr

$$Power_{expander} = 422199.3 \text{ Btu/hr}$$

Some commercial expanders can have up to 90% expansion efficiency (Turbo Expander, 2010).

### Hydrate Formation

#### Water Cooling Requirements

The cooling requirement of water is estimated as follows.

The water enthalpies before and after the cooling are obtained NIST chemistry webBook (Themophysical, 2008).

The sensible heat of cooling is estimated from

$$Q_{water} = m(H_i - H_f)$$

where

$Q$  = sensible heat of cooling

$m$  = no of moles of gas mix

$H_i$  = initial enthalpy of water

$H_f$  = final enthalpy of water

Sample calculation

For 5 MMscf/d gas mix, 79037.9 moles of water is required for hydrate formation

Water cooling from 60 F to 35 F is to be carried out.

$$m = 83046$$

$$H_i = 506.9 \text{ Btu/lbmole}$$

$$H_f = 86.46 \text{ Btu/lbmole}$$

$$Q = 83046 (506.9 - 86.46)$$

$$Q = 37535961 \text{ Btu/d}$$

$$Q = 3.75 \times 10^7 \text{ Btu/d}$$

Latent Heat of Formation Estimation

During the formation of the hydrate large amount of heat is given out which must be removed to ensure the hydrate formed do not dissociate. The latent heat of formation is estimated based on the mole fraction of the gas as a weighting factor of the heat of formation of the gas components (Makogon, 1981) shown in **Table 5**.

**Table 5**  
Estimation of Latent Heat of Formation

Sample	1		Heat of formation	Gas mix
			kJ/mol gas	kJ/mol gas
Nitrogen	N2	0.56	0.00	0.00
Hydrogen Sulphide	H2S	0.00	0.00	0.00
Carbon Dioxide	CO2	3.9	66.00	2.59
Methane	C1	92.00	54.20	49.9
Ethane	C2	2.52	81.80	2.06
Propane	C3	0.51	129.20	0.66
Iso-butane	iC4	0.10	133.20	0.13
N-Butane	nC4	0.12	133.20	0.16
Iso-pentane	iC5	0.05	0.00	0.00
N-Pentane	nC5	0.04	0.00	0.00
Hexanes plus	C6+	0.09	0.00	0.00
Total		100		55.51

The latent heat of formation of the gas sample is 55.51 kJ/mol gas (63 Btu/scf).

For 5 MMscf/d gas of sample, the latent heat is calculated as follows.

Latent heat of formation of the hydrate

$$= \text{Btu/scf gas} \times 5 \text{ MMscf/d}$$

$$= 63 \times 5,000,000$$

$$= 3.15 \times 10^8 \text{ Btu/d}$$

#### Heat Gain through Insulation

NanoPore thermal insulation provides exceptional performance with a very low overall thermal conductivity of 0.004 btu.in/ft<sup>2</sup>.h.F (Nanopore, 2010). About 240 Btu/

h of heat gained from the surroundings must be removed when using 1" thickness NanoPore material, compared to  $4.35 \times 10^7$  Btu/hr without any insulation.

### Summary of Cooling Requirement (Hydrate Formation)

**Table 6** summarizes the cooling requirement for formation of hydrate for 5 MMscf/d. The largest energy requirement is removal of the latent heat of formation which is approximately  $3.15 \times 10^8$  Btu/d. Heat gain through insulation is at about 2880 Btu/d. Overall the total cooling requirement for hydrate formation for 5 MMscf/d is  $3.53 \times 10^8$  Btu.

**Table 6**  
**Summary of Energy Requirement for Hydrate Formation**

Process	Btu/d
Latent Heat of Formation	$3.15 \times 10^8$
Water Cooling	$3.75 \times 10^7$
Gain through Insulation	$2.88 \times 10^3$
Total	$3.53 \times 10^8$

### Hydrate Dissociation

For hydrate dissociation, it estimated that the same amount of latent heat removed during the formation process is required. In this case,  $3.15 \times 10^8$  Btu/d is required for dissociation of gas hydrate storing 5 Mmscf/D.

### SUMMARY

The total energy requirement including hydrate formation and dissociation is  $6.68 \times 10^8$  Btu/d. The energy content of 5 MMscf/d gas is  $50.7 \times 10^8$  Btu/d. The overall energy requirement for the process is about 14% of the energy value of the gas transported in hydrate form depending on the composition of the gas. The value ranges from 14–20% depending on the natural gas sample.

### CONCLUSIONS

Commercial expander can have an efficiency of up to 90%. Therefore the selected expander efficiency must allow the expansion of the gas to the required hydrate formation conditions. The power developed by the expander is of the magnitude  $4.2 \times 10^5$  Btu/h.

The cooling requirement for the hydrate formation (5MMscf/d) was estimated to be  $3.5 \times 10^8$  Btu/d. About 89% of this requirement is from the latent heat of formation.

For dissociation of the hydrate,  $3.15 \times 10^8$  Btu/d is required; this represents the same amount of latent heat removed during hydrate formation.

The overall energy requirement for the process using a selected natural gas sample is about 14% of the energy value of the gas transported in hydrate form.

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