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Evaluation of the Hydrate Workflow Process Time

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Abstract

There are stranded gas reserves both on land and offshore Trinidad. Some of the fields produce associated gas which is presently being re-injected. There is need for other economic ways of capturing and transporting natural gas on a small scale especially to other small islands where there exists a Caribbean regional market for natural gas. The gas hydrate concept can be used to capture, store and transport natural gas.

The objective of the analysis is to evaluate the time breakdown for the design of an integrated scheme to transport natural gas in hydrate form Trinidad to the Caribbean islands. The study will show the time for each process in the gas hydrate value chain for transportation of 5 MMscf/d of natural gas from Trinidad to Jamaica. The evaluation shows six hours for hydrate formation, 10–20 hours for transportation and 3.6 hours for dissociation.

Key words: Trinidad; Gas hydrate; Jamaica; Associated gas

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INTRODUCTION

The need for new methods for gas transportation is the challenge that drives the development of hydrate technology for storing and transporting natural gas (Masoudi and Tohidi, 2005). The ability of natural gas to form hydrate in combination with water is a very interesting and useful concept (Makogon, 1997) which could be widely utilized in the industry. An important feature of hydrates is their high storage capacity. 180 volume units of gas at standard conditions can potentially be packed into 1 volume unit gas hydrate crystals.

Figure 1 shows the chain of Caribbean Islands where there are great potential for natural gas small scale markets.

Table 1 below captures the gas usage for power generation of some of the major players in the Caribbean region. Jamaica and Barbados are two possible markets for natural gas. Jamaica requires 25 MMscf/d while Barbados about 8.2 MMscf/d for power generation.

Table 1
Some Caribbean Countries Power Generation Needs (Energy, 2018)

Country	Electricity consumption 2012	Gas usage2012
	Billion kilowattshr	MMscf/d
Cuba	14.0	127
Jamaica	2.7	24.6
Dominican Republic	14	127
Puerto Rico	20	182
Barbados	0.9	8.2
Bahamas	1.6	14.55

The focus of this evaluation is the timing of each process using hydrate technology to capture and transport 5 MMscf/d from Trinidad to Jamaica which is about 20% of the gas needs of Jamaica.

Figure 1
Chain of caribbean islands for possible gas transportation (Caribbean, 2018)

TIME BREAKDOWN FOR THE HYDRATE PROCESS

The hydrate value chain time breakdown is show in **Figure 2** below. The formation time is estimated as six (6) hours. The time for transportation to the market (Jamaica) ranges from 10 to 20 hours depending on the location of the well in Trinidad and the location of the actual destination in Jamaica. About 3.6 hours are estimated for the time of dissociation of the hydrate and details are shown below.

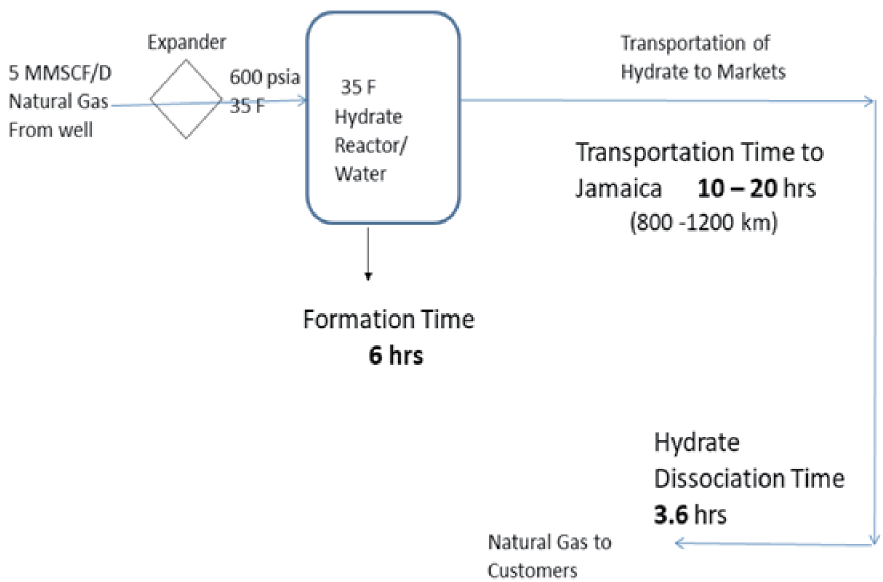

Figure 2
Time breakdown for hydrate process

Formation Time

The formation time was estimated from laboratory experiments with similar conditions to that for upscaling. **Table** 2 below shows the summary of the comparison between two laboratory experiments and potential upscaling conditions. The upscaling conditions were assumed to be similar to experiment 2 since natural gas has a higher % of methane than ethane.

Table 2
Comparison of Hydrate Formation Conditions

	Experiment 1	Experiment 2	Upscale Conditions
Composition	Ethane	Methane	99% Methane
Temperature, F	38	35	35
Pressure, psia	366	600	600
Formation Time, hr	3	5.75	6
Ratio of Surface Area / Volume	0.4	0.4	0.4

It is assumed that in the hydrate process design, the formation conditions will be 35 F and 600 psia, the hydrate formation time is estimated to be about 6 hours and a surface area to volume ratio of at least 0.4 will be used. The formation time for 5 MMscf is shown in **Figure 3**. Note the shape of the curve is s shape indication a low rate of formation at the start, then an increase in formation rate followed by a drop in rates nearing the end of the formation of hydrate cycle.

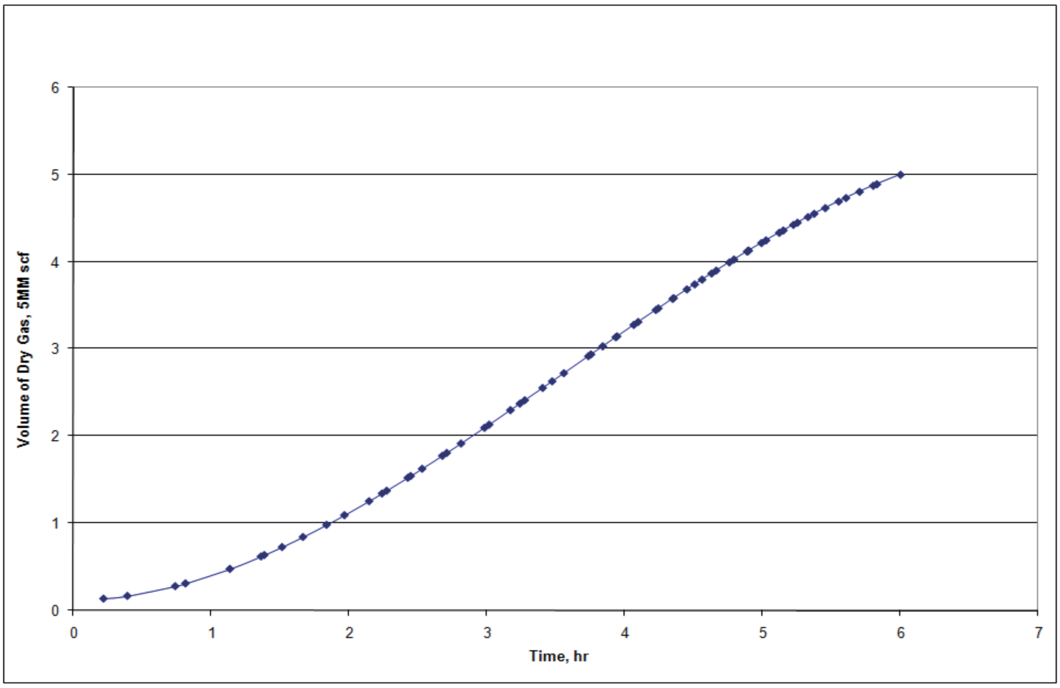

Figure 3
Formation time for 5 MMscf

TRANSPORTATION TIME

The actual transportation time from production of hydrate in Trinidad to the market in Jamaica depends mainly on:

The actual distance between the well location in Trinidad and the market destination in Jamaica. For e.g. if the gas well is off the east of Trinidad, the transportation time is longer than for a well location on the west coast or north coast. A similar situation would be seen at the market destination. Therefore it would take a longer time if it is necessary to move around the island.

The type of sea vessel used to transport the hydrate. The vessel can be built to meet the specific needs and thus with constantly improving technology there are faster and faster vessels.

If one considers an average vessel speed of 25 knots (46 km/hr) and the transporting distance ranging from 800 – 1200 km and hence the estimated for transportation of 10 to 20 hrs.

DISSOCIATION TIME

The dissociation time at the market is another key aspect to the overall gas hydrate value chain. Dissociation of the hydrate can be done through depressurization of hydrate or increasing temperature of the hydrate. In this study we only consider hydrate dissociation by increasing temperature. Faster dissociation rates would be facilitated by the heat transfer tubes that traverse the entire vessel. Hot water can be pumped through the tubes thereby increasing the temperature of the hydrate and facilitating dissociation. The dissociation temperature is estimated at 42 F for the dry gas sample from **Figure 4**. The PT curve shown in **Figure 4** shows the formation temperature and possible dissociation temperature. It is important to note here that dissociation temperature may be different for different gas samples. The key therefore is to heat the hydrate to dissociation temperature 42 F and estimate the overall time while accounting for phase change.

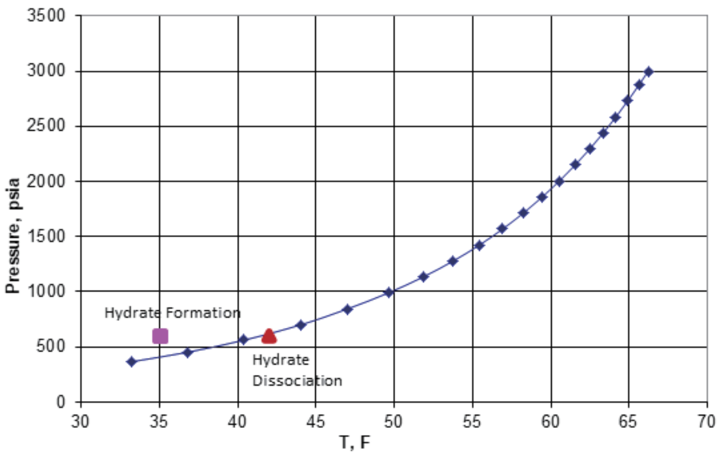

Figure 4
PT curve for dry gas sample showing hydrate formation and dissociation conditions

The model used here for estimation of dissociation is one developed to estimate the dissociation time of a hydrate plug (Hong, Gruy and Herri, 2006). A similar concept is seen between both the hydrate plug and a circular region around the heat transfer tube in the hydrate vessel.

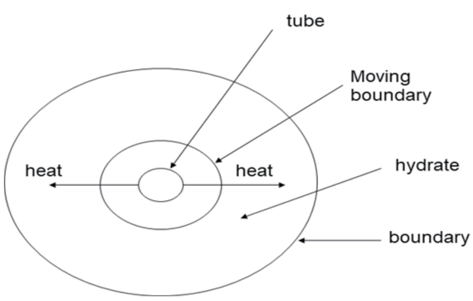

Figure 5
Dissociation schematic for one heat exchange tube

Figure 5 shows the heat transfer from one tube outwards dissociating the hydrate as a moving front. In this study heat transfer is the determining step of dissociation (Hong, Gruy and Herri, 2005).

Assumptions of the model:

• Pressure is homogeneous in the hydrate

• Hydrate around the heat transfer tubes are dissociated radially and axial dissociation is neglected.

• The temperature drop across the tube wall is negligible.

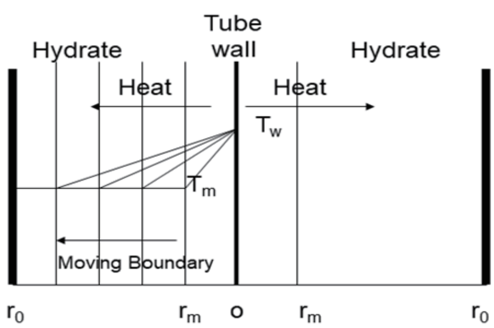

Figure 6
Hydrate dissociation with moving boundary

Figure 6 shows the schematic of hydrate dissociation with moving boundary.

At time $t > 0$, the outer surface of the heat transfer tube is maintained at a temperature T_w

So, the initial condition of this system is

$T = T_i,\ t = 0,$

and the boundary conditions are

$T = T_w, \quad r = r_0, \quad t > 0,$

$,\ ,\ t > 0$

$t > 0$

The enthalpy function H is a function of temperature T where

Another form of the enthalpy is

As the phase change is realized, a discontinuity in H is observed.

Substituting H into the heat equation, we obtained the equation of the phase change in a cylindrical two dimensional region with radial symmetry as follows:

The melting of the hydrate can be written in the following non-dimensional form as:

The dimensionless variables are defined by:

The numerical results from this scheme indicate that the dimensionless melting time t: for the circular cylinder may be approximated by the following expression:

)

The dissociation time estimated from the equation was 3.6 hrs for a 3.3 inch radius around the heat exchange tube **(Figure 7)**. With the possibility of flowing hot water through all the tubes at the same time, we can therefore estimate the total time of hydrate dissociation as 3.6 hrs. Approximately 3500 gallons of water at 80 F would flow through the 1” tubes during the 3.6 hrs dissociation period. One can therefore imagine the length of time it would take for dissociation without heat transfer tubes in the hydrate vessel. The following terms are used in the equations above:

c_L heat capacity of liquid water, btu/lb F

Porosity of hydrate, %

H enthalpy, btu/lb

K_L thermal conductivity of liquid water, btu/ft.h.F
L heat of dissociation of hydrate, btu/lb
M molar mass, kg/mol
r radial coordinate, ft
r_0 radius of hydrate around heat tube, ft
r_m radial position of phase change boundary, ft
t time, hr
t_D dissociation time, hr
T temperature, F
T_0 initial temperature, F
T_m dissociation temperature, F
T_w external tube wall temperature, F

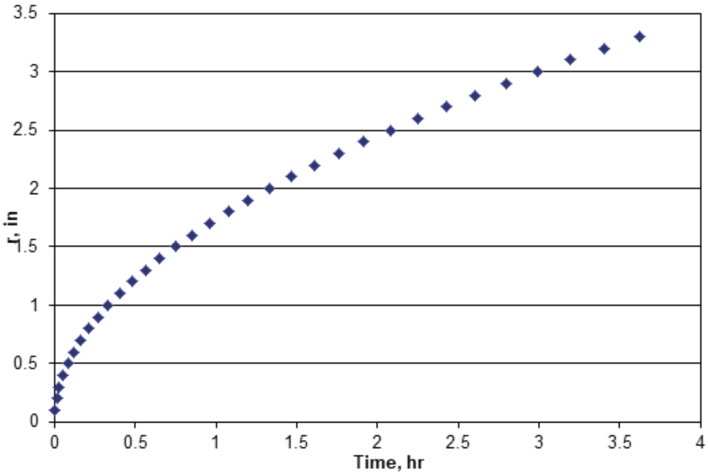

Figure 7
Time of dissociation for moving boundary

CONCLUSION

Time analysis shows six hours for hydrate formation using conditions from laboratory experiments,

About 10-20 hours is estimated for transportation of the hydrate from Trinidad to Jamaica considering an average vessel speed of 25 knots (46 km/hr)

The dissociation time is estimate at 3.6 hours using a moving boundary model for the dissociation of the hydrate at the market.

Overall it can take 20–30 hours to form, transport and dissociate 5 MMscf/d of natural gas from Trinidad to Jamaica.

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