

**LANGSON ENERGY: REPORT 28**  
**LANGSON-DI PIPPO PROCESS:**  
**HYBRID POWER GENERATION – ICE-MAKING APPLICATION**

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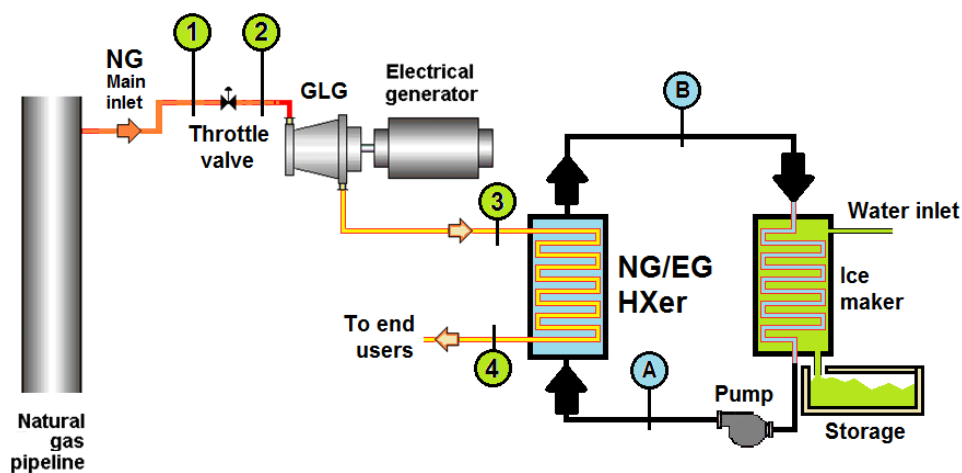
## 1. Introduction

This report examines the use of the Langson Gas-Letdown Generator (GLG) in conjunction with one of several possible chiller applications, namely, the making of ice on a commercial scale for any number of applications associated with ice. This is a subset of the manifold of applications that is being called the Langson-DiPippo process.

The results from RDP Report No. 17 will be re-examined. Two cases were studied there: one using preheating and one using postheating to avoid the extremely low temperatures that are possible at the exhaust of the GLG when expanding natural gas from a high pressure to a low pressure. If we take the postheating case and eliminate the heating after expansion, we will have a basis for the chiller assessment.

## 2. Process Flow Diagram

**Figure 1** shows the process flow in simplified form. Natural gas (NG) at an assumed pressure, temperature and composition flows to the GLG where it expands and generates electricity. It then flows to the NG/EG heat exchanger in which the extremely cold NG serves as a heat sink for an aqueous ethylene glycol (EG) solution. The NG, having been heated back to its initial temperature, then passes out of the system and continues on the end users.



**Figure 1. Flow diagram for Langson-DiPippo process: ice-making only.**

The EG solution is the working fluid in an ice-making machine. The present study is an attempt to provide some appreciation of the flow rates and temperatures that might be appropriate for this application of the GLG.

### 3. Power and Heat Calculations

**Table 1** below (Table 2 from Rep. 17) gives the state-point results obtained using a GLG with an assumed isentropic efficiency of 60% and **RefProp** for the thermodynamic properties of the assumed NG mixture (see Table 1 in Rep. 17). State 1 is the condition in the NG mains, state 2 is after a throttle valve to lower the pressure to the GLG limit inlet pressure, state 3s is the ideal isentropic expansion outlet from the GLG, state 3 is the actual outlet state, and state 4 in the table is the outlet from the postheater that was used in Rep. 17, which in this case is not used. However, the heat needed to boost the NG temperature to 60°F is exactly the amount of heat that will be absorbed from the chiller working fluid. In other words, the postheater of Rep. 17 is thermodynamically equivalent to the NG/EG heat exchanger used here.

**Table 1. Results for postheating case.**

State	Temperature	Pressure	Volume	Enthalpy	Entropy
	°F	psig	ft <sup>3</sup> /lbm	Btu/lbm	Btu/lbm°R
1	60	685	0.4234	345.37	1.0531
<b>2</b>	<b>55.133</b>	<b>600</b>	<b>0.4819</b>	<b>345.37</b>	<b>1.0668</b>
3s	-59.233	215	1.0134	297.42	1.0668
<b>3</b>	<b>-23.442</b>	<b>215</b>	<b>1.1284</b>	<b>316.60</b>	<b>1.1127</b>
<b>4</b>	<b>60</b>	<b>215</b>	<b>1.3840</b>	<b>360.83</b>	<b>1.2054</b>

The power generated by the GLG and the heat absorbed from the chiller working fluid are directly proportional to the mass flow rate of the natural gas passing through the system. As we have seen, one issue has been the specification of the NG flow rate. It has not been clear in all cases whether the quoted flow rates, usually in cubic feet per minute (CFM) are at the prevailing conditions of pressure and temperature in the NG mains or at standard pressure and temperature (STP). The difference is huge in terms of the mass flow rate.

For the present study, we will use the NG mass flow rate as a parameter. The corresponding volume flow rates, if needed, can be calculated once the NG conditions are clearly stated, using the equation:

$$\dot{V} = \dot{m}v = \dot{m} / \rho$$

where  $\dot{V}$  is the volumetric flow rate,  $\dot{m}$  is the mass flow rate,  $v$  is the specific volume, and  $\rho$  is the density.

For each value of mass flow rate, the GLG would generate the following amount of power:

$$\dot{W} = \dot{m} w = \dot{m}(h_2 - h_3)$$

Likewise, the amount of heat that will be absorbed to raise the NG temperature back to its initial temperature of 60°F will be found from:

$$\dot{Q} = \dot{m} q = \dot{m}(h_4 - h_3)$$

Bearing in mind the power limitation of the GLG, about 1,000 kW, the mass flow rates selected for the parametric study will be less than 3,500,000 lbm/h. For the conditions in **Table 1**, the following results are obtained and shown in **Table 2**.

**Table 2. GLG power and chiller heat absorbed.**

NG mass flow rate lbm/h	GLG power output kW	Chiller heat absorbed Btu/h
100,000	29.3	4,423,000
1,000,000	293	44,230,000
2,500,000	733	110,575,000
3,500,000	1,026	154,805,000

**Table 3** shows the very large differences in volumetric flow rates for these selected mass flow rates, depending on whether actual or STP conditions are used. The actual P/T conditions are 685 psig and 60°F; STP conditions are 59°F and 0 psig.

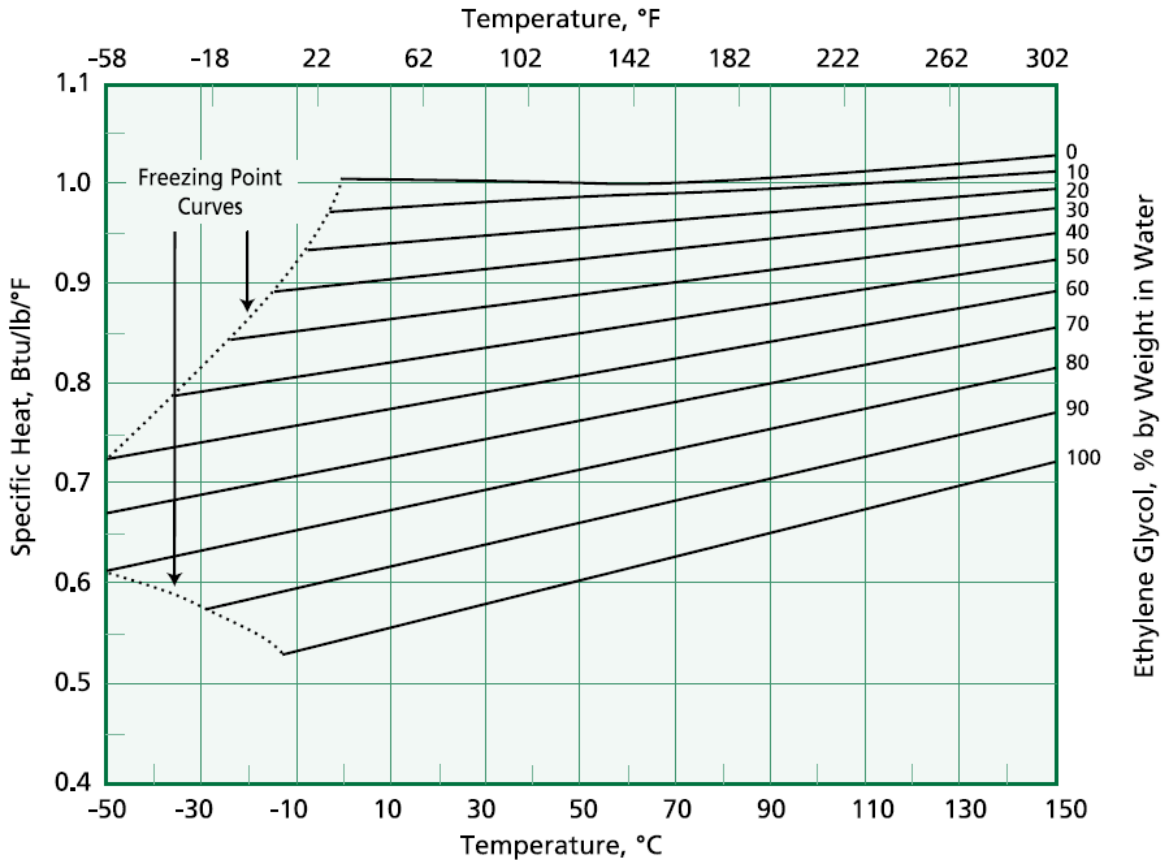
**Table 3. Effect of NG conditions on volumetric flow for given mass flows.**

NG mass flow rate lbm/h	Volume flow rate @ P/T actual CFM	Volume flow rate @ STP CFM
100,000	705.7	37,138
1,000,000	7,057	371,383
2,500,000	17,642	928,458
3,500,000	24,698	1,299,842

#### 4. Chiller Working Fluid Selection

The chiller working fluid is assumed to be ethylene glycol (EG) in water. After studying the properties of this mixture, a composition of 70% EG-30% water (by weight or mass) was selected. This liquid solution can be taken down to -58°F without freezing; see **Figure 2**. Furthermore, it is inadvisable to lower the temperature of the solution close to

the freezing curves because the solution becomes slushy. The 70% solution allows the most leeway at very low temperatures.



**Figure 2. Specific heat for aqueous ethylene glycol mixtures.** From “Ethylene Glycol Product Guide”, MEGlobal, The MEGlobal Group of Companies, 2008, page 19.

The specific heat,  $c$ , is given by a simple equation for the 70% solution:

$$c = a + bT = 0.71707 + 0.00092863T$$

where  $c$  is in units of Btu/lbm<sup>o</sup>F and  $T$  is in <sup>o</sup>F.

### 5. Mass Flow Rates and Ice Throughput Calculations

The mass flow of the EG solution is related to the heat absorbed and the temperature change of the EG solution by the equation:

$$\dot{Q}_{EG} = \dot{m}_{EG} \int_{T_B}^{T_A} (h_A - h_B) dT = \dot{m}_{EG} \int_{T_B}^{T_A} c(T) dT \Rightarrow \dot{m}_{EG} \int_{T_B}^{T_A} (a + bT) dT = \dot{m}_{EG} [aT + 0.5bT^2]_{T_B}^{T_A}$$

$$\dot{Q}_{EG} = \dot{m}_{EG} [a(T_A - T_B) + 0.5b(T_A^2 - T_B^2)] = \dot{m}_{EG} [0.71707(T_A - T_B) + 0.00046432(T_A^2 - T_B^2)]$$

This equation gives the relationship between the EG temperature change and the EG mass flow rate since the left-hand side can be found from the heat needed to raise the NG temperature back to its initial value, namely:

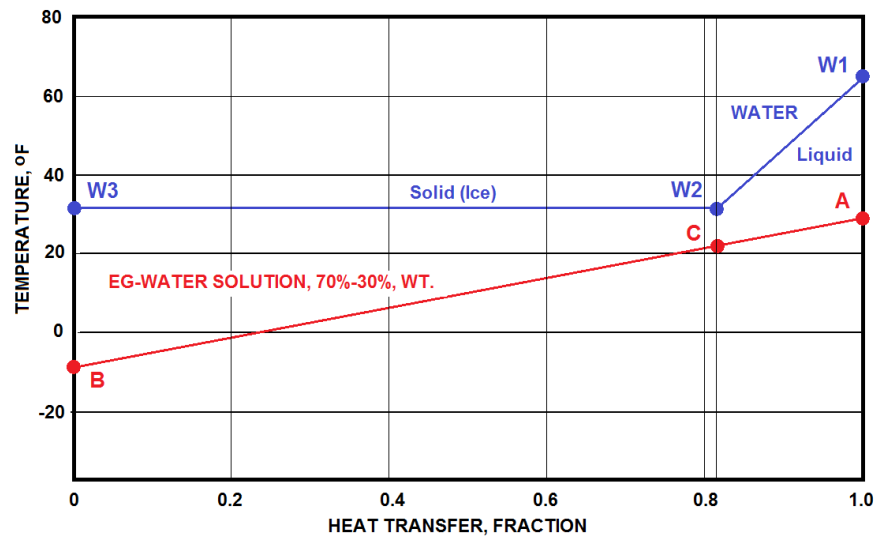
$$\dot{Q}_{EG} = \dot{Q}_{NG3,4} = \dot{m}_{NG}(h_4 - h_3) = 44.23\dot{m}_{NG}$$

We will assume a 15°F terminal temperature difference (TTD) between the EG solution and the NG at the cold end of the NG/EG HXer. Thus the EG solution leaves it at  $T_B = -8.44^\circ\text{F}$  (i.e.,  $-23.44^\circ\text{F} + 15^\circ\text{F} = -8.44^\circ\text{F}$ ).

Now we can solve these equations for the two mass flow rates in terms of  $T_A$ :

$$\dot{m}_{EG} = \dot{m}_{NG} \frac{44.23}{0.00046432T_A^2 + 0.71707T_A + 6.0190}$$

We need to find  $T_A$  by analyzing the ice-making machine. This is best done with the aid of a temperature-heat transfer (T-Q) diagram; see **Figure 3**.



**Figure 3. T-Q diagram for EG solution and water in ice-maker.**

If the EG solution is used as the heat sink for water in the ice-making machine in which the water is supplied at ambient temperature, say, 65°F (state W1), and if we allow for a 10°F pinch-point temperature difference ( $\Delta T_{PP}$ ) in the ice-maker, then the EG solution will be at 22°F at the pinch-point (where the ice just begins to form, state W2) and will enter the NG/EG heat exchanger at approximately  $T_A = 29^\circ\text{F}$ . So the two mass flows are related as follows:

$$\dot{m}_{EG} = 1.624\dot{m}_{NG}$$

Thus, we find the mass flow rates for the EG solution that correspond to each selected mass flow rate of NG; see **Table 4**.

**Table 4. Mass flow rates of EG solution for each NG mass flow rate.**

NG mass flow rate lbm/h	Chiller heat absorbed Btu/h	EG mass flow rate lbm/h
100,000	4,423,000	162,400
1,000,000	44,230,000	1,624,000
2,500,000	110,575,000	4,060,000
3,500,000	154,805,000	5,684,000

The ice-making machine may now be examined to determine how much ice could be made for each assumed NG mass flow rate. The right portion of the T-Q diagram pertains to the chilling of the incoming water down to its freezing point (W1-W2); the left side refers to the complete freezing of water into ice (W2-W3) which occurs at 32°F. Note: we are not including any subcooling that would probably be required for block ice production.

To chill the water requires the removal of 33.154 Btu/lbm while the freezing requires the removal of 143.4 Btu/lbm. Thus the pinch-point occurs where 81.22% of the heat transfer takes place (i.e., 143.4/176.55=0.8122). The mass flow rates of the EG solution and the water can be found from the heat balance on the left-hand side of the T-Q diagram, namely:

$$\dot{m}_{EG} (h_C - h_B) = \dot{m}_W \times (\text{heat of fusion})$$

The left-hand side is found by integration as before and leads to the following:

$$\dot{m}_{EG} \times 21.636 = \dot{m}_W \times 143.3$$

$$\dot{m}_W = 0.151 \dot{m}_{EG}$$

The results of the calculations are given in **Table 5**.

**Table 5. Maximum throughput of ice using the full EG solution.**

NG mass flow rate lbm/h	GLG power kW	EG mass flow rate lbm/h	Water mass flow rate lbm/h	Ice mass throughput ton/h	Ice mass throughput ton/day
100,000	29	162,400	24,522	12.3	294
1,000,000	293	1,624,000	245,224	122.6	2,943
2,500,000	733	4,060,000	613,060	306.5	7,357
3,500,000	1,026	5,684,000	858,284	429.1	10,300

## 6. Discussion and Conclusion

It can be seen that even a small GLG producing about 30 kW can be used in conjunction with an ice-making machine to produce quite a large amount of ice, namely, about 300 ton/day. Conventional commercial ice-making plants are reported to have capacities of up to 75 ton/day. Enormous and impractical amounts of ice could be produced from a maximum power 1 MW GLG. Notice that for the particular conditions studied, that the ice throughput in ton/day is roughly equal to 10X the GLG power in kW. This should not be taken as a general rule since no other conditions have been studied.

This study made no attempt to get into the fine details of ice-making except for the heat transfer requirements. Whether the ice-making is for flake, tube or block may make a difference in the arrangement of the EG solution/ice heat exchanger. Also a batch process may be used in practice in contrast to the implied steady process examined here.

Finally, of course not all of the extremely cold NG exhaust has to be used for making ice. There appears to be some balancing possible that would meet the power generating goals of the GLG together with a reasonable amount of ice-making, and still have sufficient cold EG solution available for air-conditioning and other applications.

The following two references contain interesting information:

<http://www.fao.org/wairdocs/tan/x5940e/x5940e01.htm>

<http://www.av-refrigeration.com/en/industrial-ice-machines.html>