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CO_2 and Methane Separation Using Finger-Type Slug Catcher at Seabed

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Abstract

Gas production with a very high CO2 content requires special treatment to separate the methane from CO2. The separation also requires high capital expenditure (CAPEX) and operational expenditure (OPEX). The challenge is higher, when the gas is being produced on offshore, and only narrow space that available on the platform for separation process. One proposed method to do the separation is by shifting the CO_2 phase in the phase diagram from the gas phase to the liquid phase. This shiftting requires certain pressures and temperatures that meet the temperature and pressure boundary to become liquid.

This study performs a simulation to determine the pressure and temperature constraints required to convert CO_2 from the gas phase into the liquid phase. This study uses a finger-type slug catcher mounted on the seabed. The finger-type slug catcher consists of parallel pipes of a certain diameter and length. Furthermore, the simulation is done by variations of several variables, such as: inlet pressure, ambient temperature, inner pipe diameter, and number of branches. The aim of the research is to design a slug catcher model so that the separation of methane and CO_2 gas can occur optimally. The slug catcher design resulting from this study includes the value of the inlet pressure, diameter, and minimum length of the pipe where CO_2 begin to form liquid.

The simulation was done by 320 kinds of combination for the range of inlet pressure value from 800 to 1500 psia, the range of pipe inner diameter is 40 - 50 inch, the range of ambient temperature is 50 - 80ºF, and the range of 1 to 5 number of branches. Based on the simulation, when the inlet rate of 200 MMSCFD, the inlet temperature of 100ºF and the overall heat transfer coefficient of 200 BTU/ hr / ft^2 / ºF, it is obtained the shortest length of slug catcher is 72.18 ft, 40-inch inner diameter, and the inlet pressure requirement is 1000 psia. Furthermore, for design purposes, the slug catcher length is made 217 ft to ensure that the liquid CO_2 formed at 72.18 ft from the inlet and the liquid can accumulate and keep flowing towards the end of the pipeline for further utilization.

Keywords: CO_2 phase, finger-type slug catcher, ambient temperature

1. Introduction

Gas produced with high CO2 content will give an impact on economical aspect at a field. Indonesia has high potency to produce gas with high CO2 content, such as at Natuna field and it becomes an economically challenging. Advance gas separation had been developed lately to sweet gas with high CO2 content, such as Cyrogenic, Syngas, dan Cyrocell (Amin, Jackson, and Kennaird, 2005). However, these processes are expensive to be implemented at field. Therefore, an affordable CO2 separation process is required to sustain the economic revenue in a gas field with high CO2 content.

Utilizing low seabed's temperature, gas with high CO2 content is being transported using pipeline with low temperature and high pressure to ensure the CO2 phase is liquid. However, methane will be kept in a gas form. The gas and liquid phase will be separated and the CO2 in the liquid form can be utilized further. This study was conducted to observe the phase changing of CO2 flowing in a pipe from gas to liquid and determine the key parameters design, such as: minimum inlet pressure, temperature ranges at seabed, number of branches for slug catcher design, and minimum pipe length. Those specification then is used to design slug catcher with finger-type.

2. Method

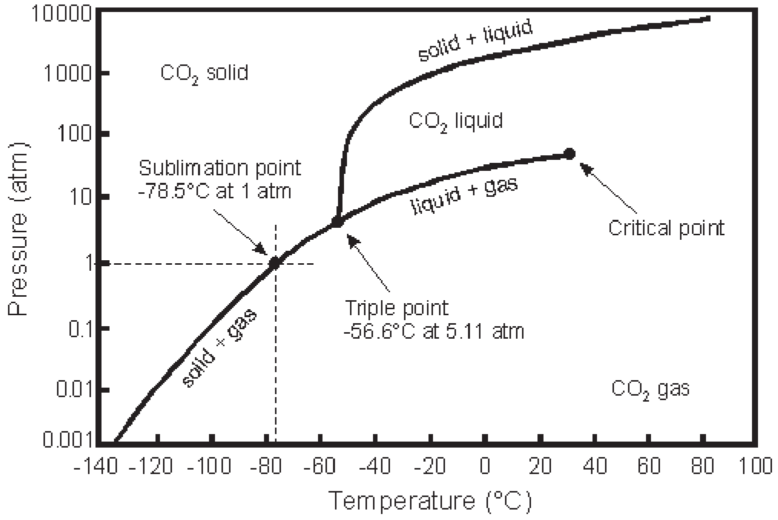
The design will be conducted using commercial simulator Pipesim^{TM}. The analysis of pressure and temperature profile to obtain minimum pipe length at ambient temperature. Optimum design of slug catcher will be obtained from sensitivity parameters. Several assumptions are used in the research: (1). mass flowrate is constant at a certain time, (2). no leakage and corrosion on the pipe, (3). pipe is able to handle high temperature, (4). no water content therefore no hydrate form, (5). no limitation on number of branches. Table 1 shows range values of sensitivity parameters. Optimum criteria for the design are defined when the CO2 is on the form of liquid using the smallest inlet pressure and shortest pipe length.

Table 1. Range values of sensitivity variables

Variabel	Range Input	Unit
Branch atau jumlah cabang	1-5	-
Inner diameter pipa	10-40	Inch
Temperature ambient	50-80	°F
Tekanan *inlet*	800-1500	Psia

2.1 CO2 Characterization

CO2 can be changed into solid, liquid or keep at gas form depends on the given temperature and pressure on the conduit. Figure 1 shows the correlation between temperature and pressure for CO2 with phase form. The pure CO2 occurs at -69.83 °F and 75.20 psia. Critical point for pure CO_2 occurs at 87.854 °F and 1070.379 psia.



Pressure-Temperature phase diagram for CO_2.

Figure 1. Phase diagram for CO_2 (https://stevengoddard.wordpress.com/2010/09/05/)

2.2 Looped Pipeline System

Parallel pipe schematic could be used to reduce flowrate. This configuration will devide flowrate into each branch using Equation 1. Mathematically, using Panhandle B equation, flowrate q_T can be represented in Equation 2. Diameter and pipe length for the parallel pipes have the same values for pipe A and pipe B. Therefore, the flowrate at pipe A and flowrate at pipe B are the same and can be represented using Equation 3. If there were n parallel branches, each branch will have flowrate value that is presented using Equation 4. Figure 2 depicts the closed pipe system that combine two parallel pipes with two series pipes.

$$q_T = q_1 + q_2 + q_3 + \cdots + q_n \text{.........} \ (1)$$

$$q_T = 737\ E \left(\frac{T_B}{P_B}\right)^{1.02} \left[\frac{P_1^2 - P_2^2}{\gamma_g^{0.961} \bar{T} \bar{Z}}\right]^{0.51} \left[\frac{(D_A^{2.53})}{(L_A^{0.51})} + \frac{(D_B^{2.53})}{(L_B^{0.51})}\right] \text{.........} \ (2)$$

$$q_A = q_B = \frac{q_T}{2} \text{ ....} \ (3)$$

$$q_A = q_B = \cdots = q_n = \frac{q_T}{n} \text{ ....} \ (4)$$

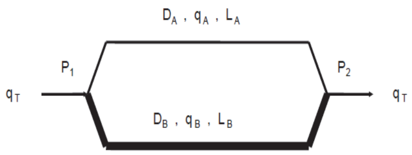


Figure 2. Looped pipe system schematic

Heat transfer is assumed occurred under steady state condition between fluid inside pipe with environment due to differences at bulk fluid temperature (T_b) and ambient temperature (T_a). Heat transfer (Q) for each pipe segment is presented at Equation 5. Heat transfer coefficient (U) is a combination from all system (parallel and series pipes). Heat transfer will give an impact on fluid cooling time inside the pipeline. The higher the heat transfer coefficient, the faster the heat transfer to happen. Therefore, the fluid temperature inside the pipe will have the same value as ambient tempareture, for short length of pipe. Figure 3 shows the changing of temperature at pipeline as an effect of heat transfer between fluid inside the pipeline to the environment.

$$Q = UA(T_b - T_a) \text{ ....} \ (5)$$

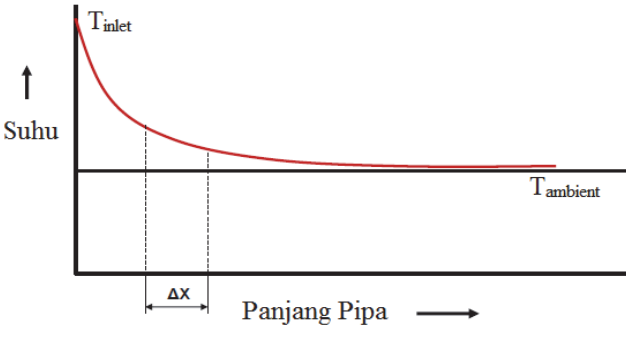


Figure 3. Temperature profile along pipeline

2.3 Slug Catcher

Figure 4 shows four branches finger-type slug catcher. Gas-Liquid separation section is used to separate liquid and gas phase. There are three types of slug catcher: vessel type, multi-pipe type or finger type, and parking-loop type. Vessel type has single-big tube or more complex type compared to the others. Multi-pipe or finger type is used to separate huge liquid volume from gas compared to vessel type. This type consists of parallel pipes with specific length and there is an outlet for liquid at the end of each pipe segment. Parking-loop type is a vessel type that restore liquid separation at a pipe similar to finger type in a circle (Jari et. al., 2009).

2.4 Data for Simulation

The simulations were conducted using data on Table 2 and Table 3. Table 2 shows constants variable such as gas rate, overall heat transfer coefficient, and inlet temperature. Gas hydrocarbon composition is shown in Table 3.

Table 2. Initial simulation data

Gas Rate (MMSCFD)	200
Overall Heat Transfer Coefficient (BTU/hr/ft^2/^{o}F)	200
Inlet Temperature (^{o}F)	100

Tabel 3. Inlet gas composition

Hidrokarbon	Mol (fraksi)
Hidrogen Sulfida	0.0143
Karbon Dioksida	0.7122
Metana	0.2718
Nonana	0.0017

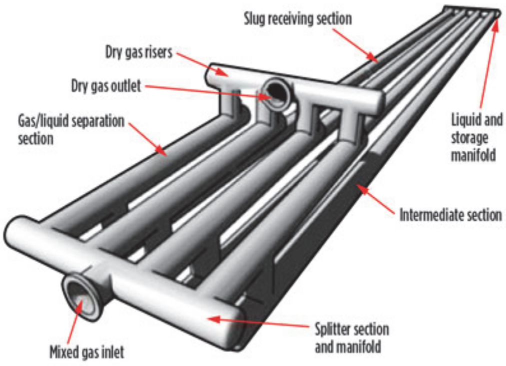


Figure 4. Finger type Slug Catcher (Jari et. al., 2009)

3. Results

There are five scenarios that will be simulated. Each scenario represents number of branches of parallel pipes, as shown in Figure 5. Data variation will give 320 combination cases. Latest condition is a condition where the temperature and pressure of gas inside pipe fulfill minimum criteria to become liquid phase. Simulation results will give length of the pipe that is required to obtain latest condition. Figure 6 shows that pipe with diameter 10 in gives high pressure drop before branching. Therefore, there is huge pressure drop between branch 1 and branch 5. Pipe with diameter 10 in gives liquid phase for inlet pressure 1300 psia and 1500 psia for any temperature, diameter and number of branches. Figure 7 shows by increasing pipe diameter will reduce pressure drop before and after branches. Increasing diameter means slowing down the gas velocity and then shorter the distance to achieve ambient temperature. As a result, as if the pressure drop is smaller.

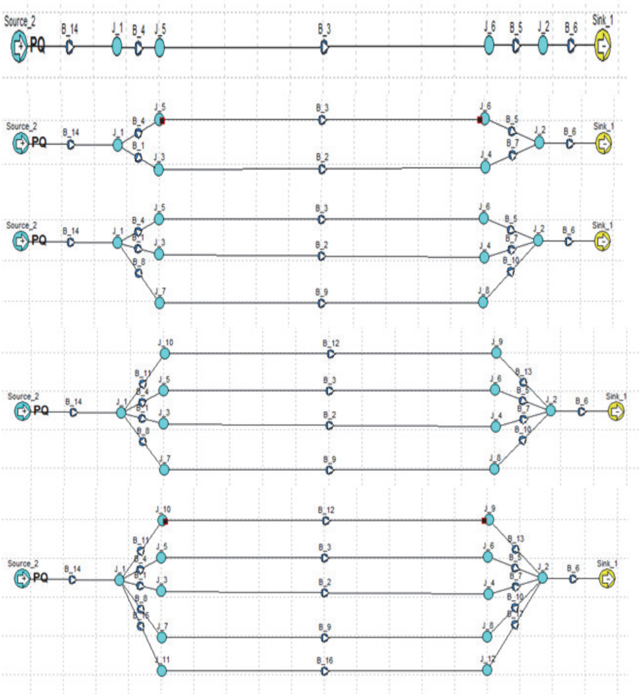


Figure 5. Simulation model from 1 to 5 branches

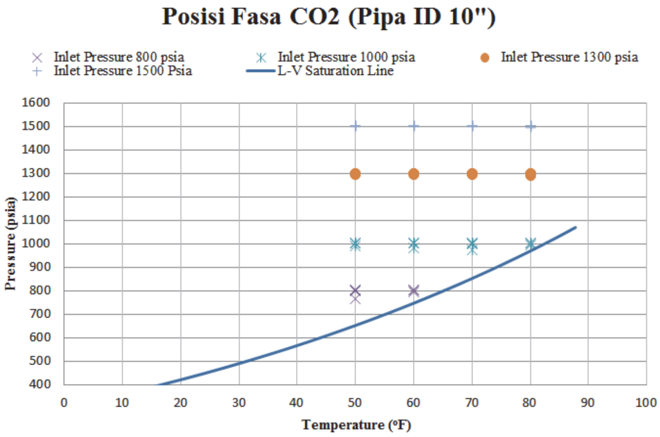


Figure 6. Phase of CO2 using pipe with diameter 10 in.

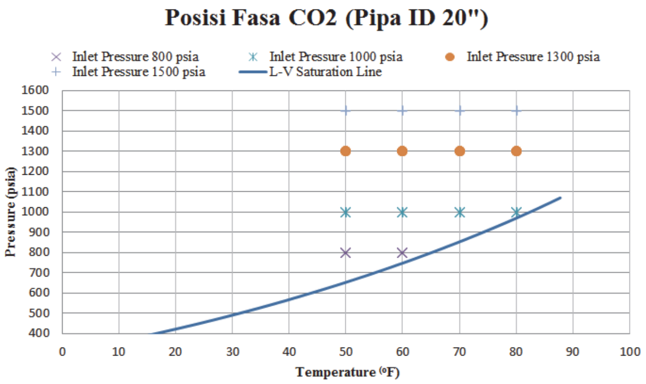


Figure 7. Phase of CO2 using pipe with diameter 20 in.

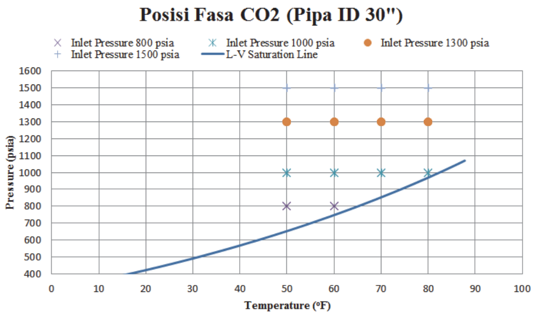


Figure 8. Phase of CO2 using pipe with diameter 30 in

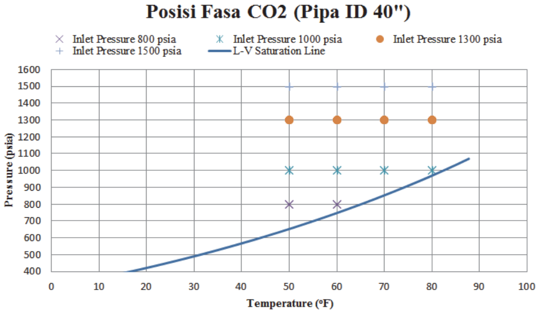


Figure 9. Phase of CO2 using pipe with diameter 40 in

Figure 8 and Figure 9 consistently show by increasing pipe diameter will reduce pressure drop before and after adding a branch. These figures also show that at ambient temperature 60 °F dan 70°F will not produce CO2 with liquid phase when inlet pressure 800 psia, for any number of branches and diameter size. Inlet pressure of 800 psia also can not used to change CO2 phase from gas to liquid at ambient temperature 70 °F and 80°F, neither for 1 branch nor 5 branches. This is due to liquid – vapor line has minimum pressure 853.45 psia at 70 °F and 970.05 psia at 80°F for CO2 no change into liquid phase. Inlet pressure of 1000 psia, 1300 psia, and 1500 psia able to change phase of CO2 from gas into liquid for ambient temperature 50°F to 80°F for any number of branch.

Simulation results also show that by adding number of branches consistently reduce minimum pipe length required to obtain temperature and pressure of CO2 at liquid phase. Figure 10 shows two times decrease of minimum pipe length from single branch and two branches. Adding more number of branches will reduce pipe length, however gives insignificant decreasing ratio. Adding number of branches will lowering gas flowrate, therefore heat transfer happens faster. Ambient temperature gives influence on determining minimum pipe length. The higher the ambient temperature, the longer minimum length of pipe. This is due to heat transfer will slower (temperature difference is small).

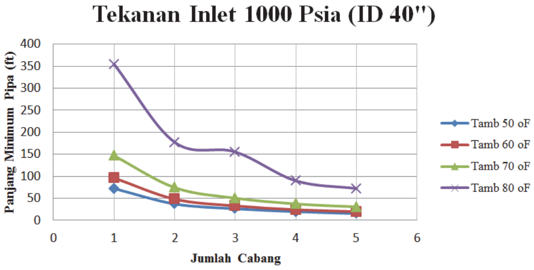


Figure 10. Profile of Minimum pipe length and ambient temperature at inlet pressure of 1000 psia and inner pipe diameter 40 in

Figure 11 shows temperature profile using inlet pressure 1000 psia. Mazimum temperetaure of CO2 becomes liquid is 82.43°F. Pipe with the same size, inlet pressure, and number of branches will have different minimum length of pipe due to ambient temperature effect. The lower the temperature, the lesser the minimum length of pipe.

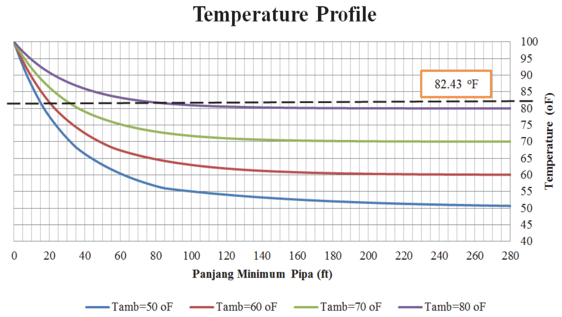


Figure 11. Tempertaure profile at inlet pressure 1000 psia, pipe ID 40 in and number if branches is five.

Figure 12 show pipe size that fulfill optimal criteria that is pipe with diameter 40 in at inlet pressure 1000 psia with number of branches is five. Using this diameter, the range of minimum length of pipe is 15.31 ft to 72.17 ft to fulfill ambient temperature between 50 °F to 80 °F to change CO2 phase from gas to liquid. Figure 13 shows using pipe diamtere 40 in required additional minimum length of pipe to accommodate with sudden ambient temperature changes. In order to accommodate sudden change of ambient temperature from 50 °F to 80 °F is chosen minimum length of pipe 72.17 ft.

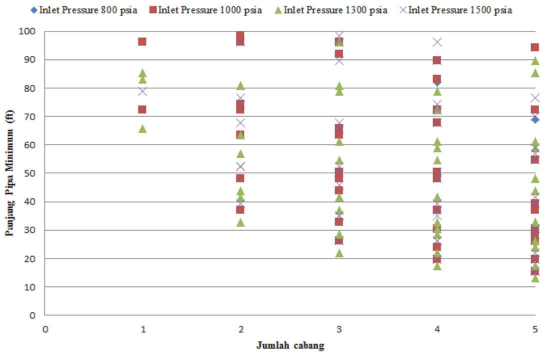


Figure 12. Minimum length of pipe VS number of branches

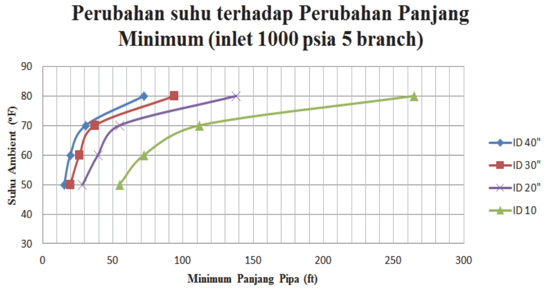


Figure 13. Effect on temperature changes on minimum length of pipe at inlet pressure of 1000 psia for five number of branches

These simulations determine design of length on slug catcher on liquid/gas section, diameter size, and minimum gas inlet pressure. CO2 liquid occurs at this minimum length. Mowing onward, due to density differences between gas and liquid will make liquid phase goes down onto down-side of pipe and moving together with methane. All liquid formed form the system must be able to be separated. A design factor, three times higher than minimum length of pipeis 217 ft (as it is shown at Figure 14) with number of branches is five and pipe diameter 40 in. CO2 separation could be used for CO2 injection in order to maintain reservoir pressure. CO2 phase will change into super-crytical when CO2 arrives at reservoir. CO2 injection system using finger type slug catcher is presented at Figure 15.

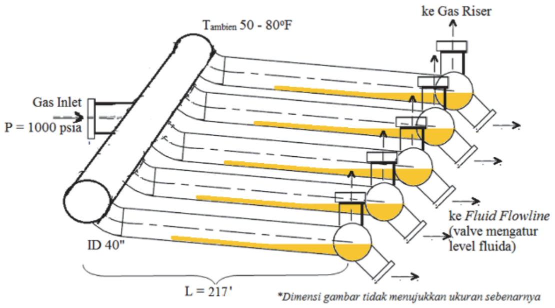


Figure 14. Finger type slug catcher design based on simulation results.

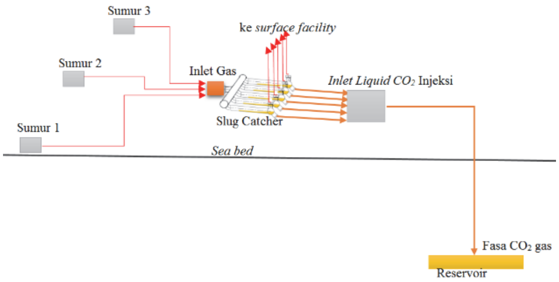


Figure 15. Integration of CO2 separation process for pressure maintenance injection purposes.

4. Discussion

Separation of CO2 and methane using the concept of gas flow in the finger type slug catcher at the seabed can be done. This can be done by utilizing the CO2 phase change from the gas to the liquid due to the ambient temperature of the seabed low enough and the high pressure applied to the gas. The addition of the number of branches and the addition of pipe diameter will accelerate the gas temperature inside the pipe to equal the ambient temperature thus shortening the minimum distance of the pipe required for the CO2 phase to begin to turn into liquid. The optimal size obtained for the case in this study is the minimum length of the required finger slug catcher pipe is 72.17 ft, with a pipe diameter of 40 inches, and the number of branches is 5. This size applies to inlet pressure at least 1000 psia and ambient temperature 50 -80ºF. Consideration of the design factor, then the length of the design of the finger type slug catcher is 217 ft. Due to limitations of design variables in this study, the liquid phase CO2 can be formed is under the following conditions:

1) Inlet Pressure 1500 psia and 1300 psia, Temperature 50-80ºF, pipe ID 10-40 inch, and number of branch 1-5.

2) Inlet Pressure 1000 psia, Temperature 50-80ºF, pipe diameter 10-40 inch, branch number 1 (except when the size of 10 inch pipe, the number of branches must be more than one) to 5.

3) Inlet pressure 800 psia, Temperature 50-60ºF, 10-40 inch of pipe diameter, number of branches 1 (except 10 inch ID size pipes, branches should not be 1 at 60oF) to 5.

Acknowledgments

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Symbol

A = keliling terluar pipa (ft)

D = diameter pipa (ft)

E = efisiensi aliran dalam pipa (0-1)

L = panjang pipa secara horizontal (ft)

n = jumlah cabang pipa

P = tekanan di suatu *section* pipa (psia)

Q = transfer panas setiap unit panjang pipa (BTU/hr/ft)

q_n = laju alir gas pada cabang ke-n (MMSCFD)

q_T = lajua lair total (MMSCFD)

T = temperature (°R)

U = *overall heat transfer* (BTU/hr/ft^2/°F)

$\bar{Z}$ = faktor deviasi gas pada T dan P rerata

γ_g = spesifik gravitasi gas

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