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Cite as: AIP Conference Proceedings **2223**, 040005 (2020); https://doi.org/10.1063/5.0000852
Published Online: 06 April 2020

Luthfi Kamal Bangkit Setyawan, Abdul Wahid, and Widodo Wahyu Purwanto

Dynamic Simulation and Control of Unloading and Holding Small-Scale Onshore LNG Regasification Processes

Luthfi Kamal Bangkit Setyawan[1,2, a)], Abdul Wahid[2,b)] and Widodo Wahyu Purwanto[1,2,c),*]

[1]*Sustainable Energy System and Policy Research Cluster, Chemical Engineering Department, Universitas Indonesia, Depok, 16424, Indonesia*
[2]*Chemical Engineering Department, Faculty of Engineering, Universitas Indonesia, Depok, 16424, Indonesia*

[a)]luthfi.kamal@ui.ac.id
[b)]wahid@che.ui.ac.id
Corresponding author: [c)]widodo@che.ui.ac.id

Abstract. The problem encountered on the regasification terminal is unsteady operating because of unloading from LNG carrier to storage and holding mode that involves the on-off operation of Ambient Air Vaporizer (AAV) caused by frosting. The purposes of this study are to simulate a dynamic operation of small-scale regasification terminal using AAV with and without controls by process simulator UniSim. The result of the simulation without controls, shows that the gas flow rate has deviated 14% from the target, after 4 hours of operation output gas temperature is below 2.5°C, it cannot meet the requirements of the gas power plant. For simulation with controls, a digital on-off type controller is used for pump during unloading and switch or on-off between AAV, while PI type controller is used to control LNG flow rates. For the digital on-off controller, the controller is set to stop the unloading process when the remaining LNG in the carrier is 10% (350m^3) and the other digital on-off controller will be set to act on switching AAV when the AAV gas sent out temperature reaches 3°C. For PI controllers, the tuning parameters to regulate the flow rate is Kc = 0.00638 and Ti = 0.00043. The maximum operating time for 1 AAV is 5 hours 15 minutes before it will be switched for defrosting and replaced with other AAV. After the controller installed, the gas sent out specifications from the terminal able to meet the requirements of the power plant, a molar flow rate of 6.53 MMSCFD and a minimum gas temperature of 2.5°C throughout the operating time.

INTRODUCTION

To fulfill energy demands in Indonesia, a variety of resources are being used in the national energy mix, including coal (33%), oil (37%), natural gas (22%) and renewable energy (8%) [1]. Natural gas has an important role and it produces half the emissions of coal per kWh. If natural gas is being used as a source of energy, the result is a 40% decrease in total emissions, even with some coal remaining in the system [2]. Liquefaction of natural gas into their liquid phase (LNG) is one of the methods used to reduce the volume and simplify the transportation of natural gas. Before LNG being utilized as a fuel source for power plants, the regasification terminal is needed to change back the LNG into the gas phase. LNG can be supplied for remote areas by using small scale LNG infrastructure. The small scale terminal configuration uses main equipment such as pressurized tank and Ambient Air Vaporizer (AAV) for their operation.

A common problem that usually occurred in the regasification terminal is an unsteady operating condition due to two terminal conditions, which are at LNG unloading from the carrier to storage (unloading mode) and when LNG in storage is sent to LNG vaporizer (holding mode). Moreover, the application of AAV type of vaporizer may also cause unsteady conditions, due to the formation of the ice layer (frosting) at tubes of the AAV. This ice layer is formed from water contained in the air. Frosting affects the decreasing heat transfer coefficient that causes

International Energy Conference ASTECHNOVA 2019
AIP Conf. Proc. 2223, 040005-1–040005-6; https://doi.org/10.1063/5.0000852
Published by AIP Publishing. 978-0-7354-1982-7/$30.00

decreasing gas output temperature from AAV over time. Therefore, the process control system is required to meet requirements that feed gas operating conditions for a power plant. For a gas turbine power plant minimum temperature and pressure are 2.5°C and 20-28 barg [3], respectively.

Wahid et al. [4] did a dynamic simulation of the LNG regasification terminal using Open Rack Vaporizer (ORV) for the vaporizer, and Model Predictive Control (MPC) for the controller. The results show that MPC controllers can save energy about 0.02 MW when a disturbance in temperature of seawater is rising 1°C.

This study aims to simulate the dynamic operation of small scale onshore LNG regasification terminal using Ambient Air Vaporizer (AAV) with and without process control system. The presence of process control of gas output in the regasification terminal is expected to fulfill the requirement of feed gas for gas turbine power plants.

METHODOLOGY

Figure 1 presents a schematic diagram of the unloading and holding process of a small scale LNG regasification terminal. LNG from the carrier will be transferred to pressurized tanks at a regasification terminal using pumps. The LNG would then be sent through a pump to the AAV, for evaporating LNG into the gas phase. The unloading and holding process is simulated using UniSim Design with an Equation of State of Peng-Robinson. The results of the simulation are expected to be dynamic behaviors from the LNG regasification terminal including molar flow, temperature, and pressure of the gas over time.

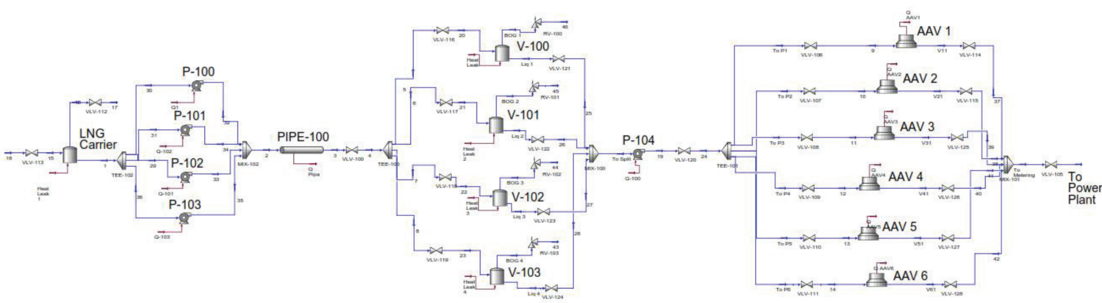


FIGURE 1. Flowsheet of a small-scale onshore LNG regasification terminal

Process Simulation

The gas sent out of 6.53 MMSCFD from this LNG terminal used to supply gas for a gas turbine power plant with 50 MW capacities, 70% capacity factor (CF), located at Nias island. The distance between Bontang and Nias Island is 1,890 nm (3,500 km) [5]. With the typical speed of a small LNG carrier that is 15 knots [6], it takes around 129 hours (5 days) to ship LNG from Bontang to Nias Island. The total time needed for 1 time round trip is around 10 days. 3,500 m^3 LNG carrier capacity used to transport LNG from Bontang LNG plant to regasification terminal with a roundtrip of 10 days corresponding to 1,200 m^3 of LNG storage of LNG regasification terminal. The composition of Bontang LNG is listed in Table 1 [7].

TABLE 1. Composition of Bontang LNG

Component	Composition (% mol)
Methane	91.66
Ethane	4.48
Propane	2.72
i-Butane	0.54
n-Butane	0.56
Nitrogen	0.03
Total	100

The main problem faced in this research is UniSim Design does not provide process equipment that can represent a frosting phenomenon of the AAV. Therefore, an approach to the frosting phenomenon from AAV will be carried out by using a feature named event scheduler in UniSim Design. An approach for AAV frosting phenomenon is in form of a decrease in K value (local overall heat transfer coefficient consisting of convective heat transfer of LNG inside tube, conductive heat transfers in tube wall and frost layer, and convective heat transfer of air in external side) of AAV over time using data provided by previous research [5Shansan]. Then, the overall heat transfer coefficient at a given time using equation 1.

$$U = \frac{1}{X}\int_0^X K dx \tag{1}$$

where U is the overall heat transfer coefficient, X is the length of the AAV tube, K is the local overall heat transfer coefficient. The decrease in U value will be integrated into UniSim Design using the event scheduler feature.

PI type and digital on-off type controllers are chosen because PI type controller can handle almost all process control conditions, quickly return the set point of LNG molar flow to its supposed values after a disturbance or setpoint change occurs, and cheaper than the PID and MMPC type controllers. The tuning method used for the PI controller is Tyreus-Luyben Tuning Method. This method is based on the sustained oscillation of the system response. The closed-loop system under a proportional controller is driven to a critically stable state by increasing the proportional gain with an integral time constant (*Ti*) set to infinity and derivative constant (*Td*) set to 0. The corresponding gain and period at this point are referred to as the ultimate gain (*Ku*) and ultimate period (*Pu*). The ultimate gain and ultimate period are used to calculate the PI tuning parameters as shown in Table 2.

TABLE 2. Tyreus-Luyben tuning rules for PI

Type of Controller	Kc	Ti
PI	Ku/3.2	2.2Pu

The digital on-off type controller is chosen because it can be used when the variable controlled does not require precise results at the desired value. This type of controller is used to control the unloading pump and switch between AAV when the gas sent out a temperature approach to 3°C and to control the unloading process. List of variables to be controlled, type of controller, and final element are listed in Table 3.

TABLE 3. Controlled variable, type of controller, and final element

Controlled Variable	Type of Controller	Final Element
LNG Level in Carrier	Digital on-off	On-off Pump
Gas Molar Flow Rate	PI	Valve opening percentage
Gas Temperature	Digital on-off	On-off AAV valve

RESULTS AND DISCUSSION

Summary of the infrastructures used and the capacities of this regasification terminal are shown in Table 4.

TABLE 4. Infrastructures and capacities

Infrastructures	Amount	Parameters
LNG Carrier	1	Capacity: 3,500 m^3, Pressure: 7 bar
Unloading Pumps	4 (2 operate, 2 standby)	Throughput: @300 m^3/h
Pressurized Tank LNG at Terminal	4	Capacity: @1,200 m^3, Pressure: 8 bar
Pump to Ambient Air Vaporizers	1	Throughput: 20 m^3/h
Ambient Air Vaporizers	6	Throughput: @2.178 MMSCFD

Based on previous research [8], the overall heat transfer coefficient value is modeled by polynomial equations for each time using equation 1. The models of the heat transfer coefficient for a given hour are shown in Table 5.

TABLE 5. Model of local overall heat transfer coefficient

Time (h)	Equation	Overall Heat Transfer Coefficient (U) (W/m^2K)
1	$K = 0.0008X^4 - 0.1476X^3 + 10.558X^2 - 333.91X + 4130.8$	163.87
2	$K = 0.0005X^5 - 0.104X^4 + 9.514X^3 - 431.45X^2 + 9695.4X - 86107$	146.57
4	$K = -0.0008X^5 + 0.1694X^4 - 14.905X^3 + 647.54X^2 - 13874X + 117329$	138.96
8	$K = -0.0003X^5 + 0.0654X^4 - 6.2663X^3 + 294.66X^2 - 6790.2X + 61391$	118.67

where K is the local overall heat transfer coefficient and X is the length of the AAV tube. Based on the calculation, it was found that the decrease in U values for 8 hours is almost 28%.

Dynamic Simulation Without Controller

The dynamic simulation results of gas sent out and its temperature are shown in Fig. 2. It can be seen that the flow rate of 7.45 MMSCFD and temperature of -16°C of gases didn't meet the requirement of the power plant, therefore process control will be carried out.

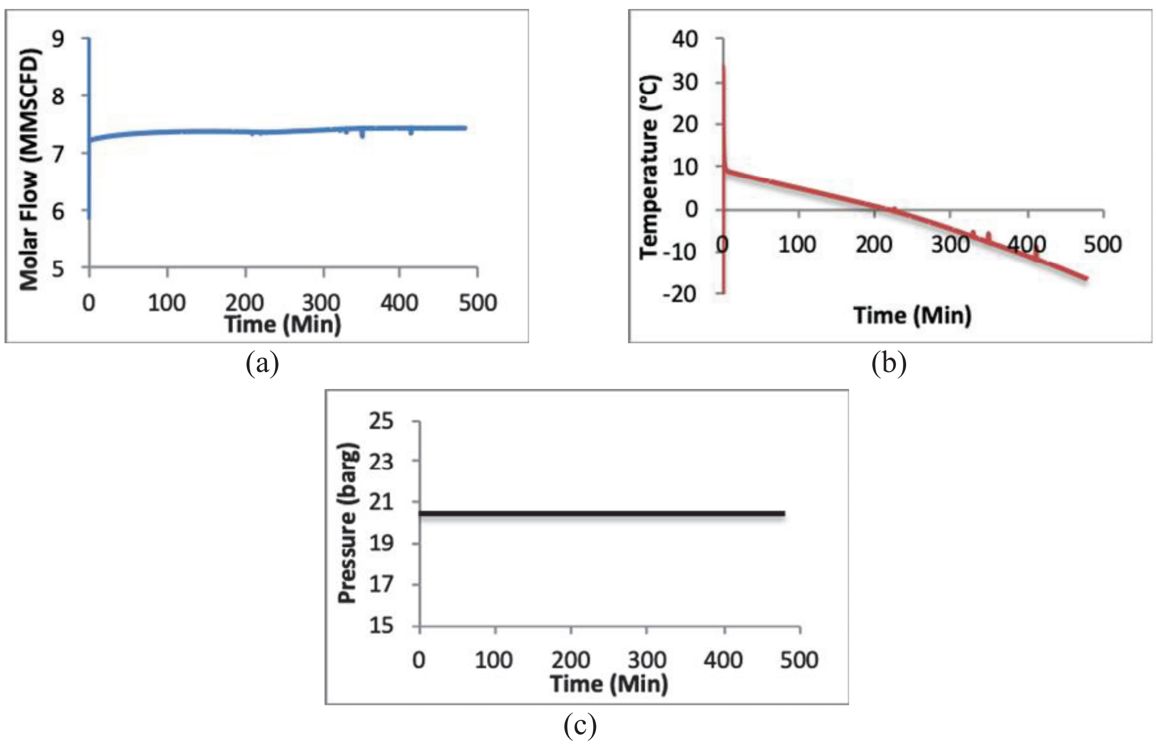
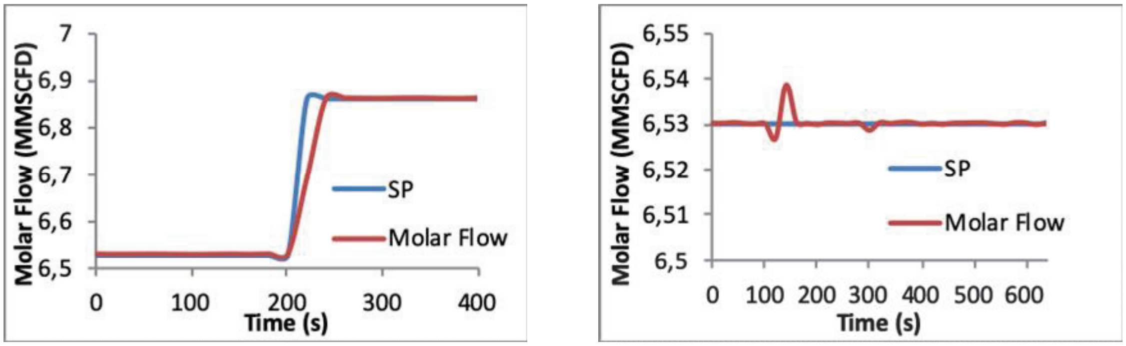


FIGURE 2. Dynamic simulation result: (a) Molar Flow; (b) Temperature; (c) Pressure

Process Control

The process control is done with a PI type controller to control the molar flow rate of gases at a setpoint of 6.53 MMSCFD. Tuning parameters (Kc and TI) for PI controller can be obtained by using an auto-tuner feature in UniSim Design. With auto tuner feature, tuning parameter value of Kc = 0.00638 and TI = 0.00043 are obtained. This value of tuning parameter will be tested to see how the controller responds when there is a change in setpoint and a disturbance. After testing, it can be seen that the controller gives a good response. Respond of the controller are shown in Fig. 3.



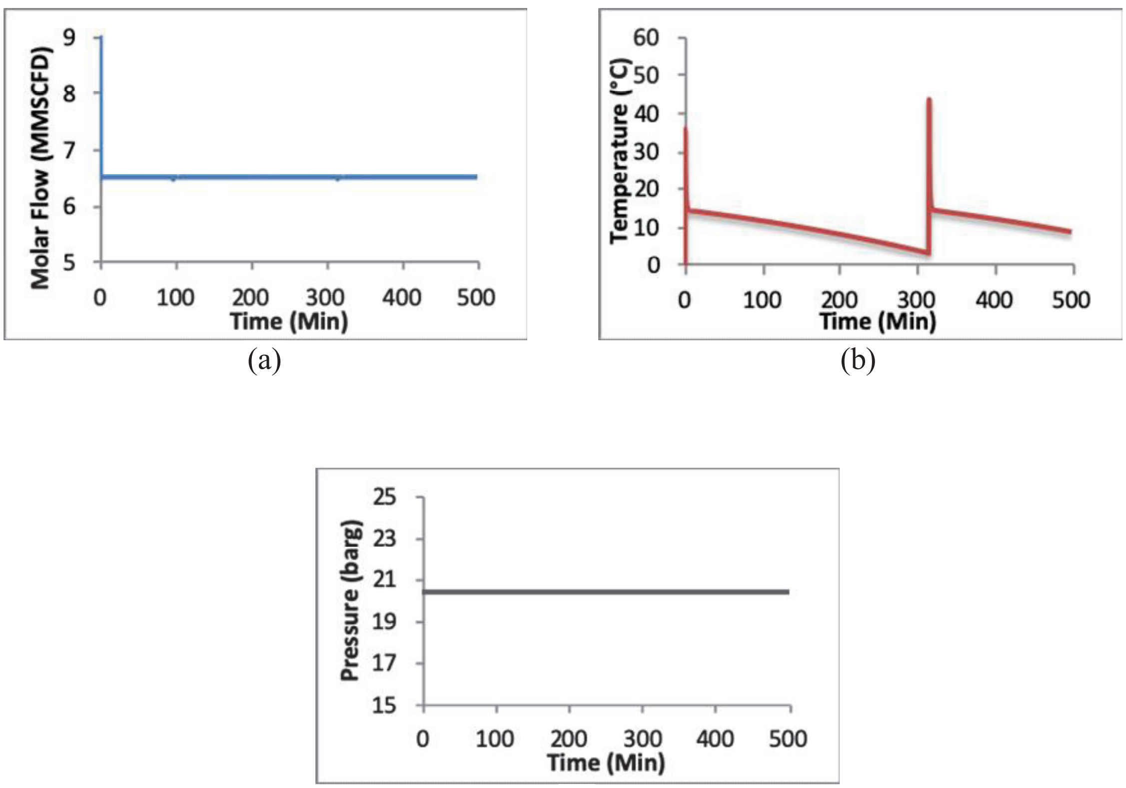
(a) (b)

FIGURE 3. Controller respond due to (a) Set point change; (b) Disturbance

The digital on-off type controller is used to take switch action between two AAVs when the outlet gas already near 3°C. Gas sent out specification is able to meet the requirement of the power plant.

Dynamic Simulation with Controller

The dynamic simulation results with controllers are shown in Fig. 4.

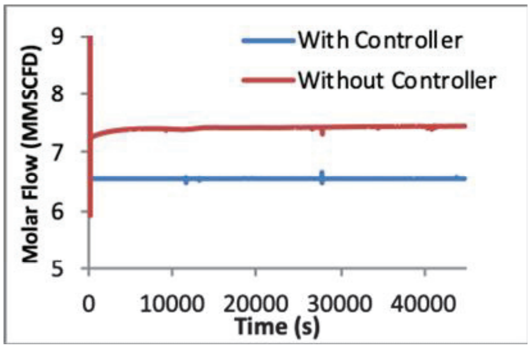


(a) (b)

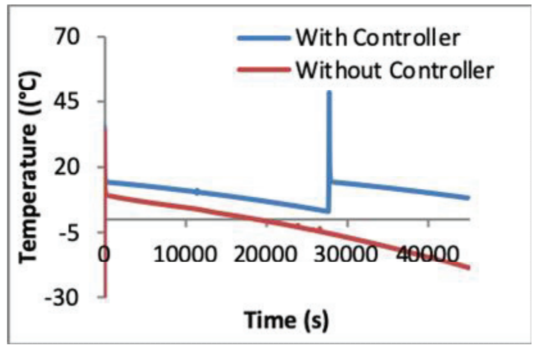
(c)

FIGURE 4. Dynamic simulation with controllers result: (a) Molar Flow; (b) Temperature; (c) Pressure

Figure 5(a) shows the comparison of the molar flow rate of gas sent out from the regasification terminal when it is controlled and not controlled. For the system without controllers, the gas sent outflow rate deviates 14% from the set point. After the installation of controllers, the gas sent outflow rate to become stable at 6.53 MMSCFD. Figure 5b displays the comparison of gas sent out the temperature of the system with controllers and without controllers. In the case of a system without controllers, the sent out gas temperature of AAV decline over time, after 4 hours the temperature becomes less than 0°C and it cannot fulfill the requirement of the power plant. With controllers, the sent out gas temperature greater than 2.5°C for all times, with maximum operating time for each AAV is 5 hours 15 minutes before it will be switched for defrosting and it is replaced with other AAV.



(a)



(b)

FIGURE 5. Comparison of sent out gas dynamics with and without a controller: (a) Molar flow; (b) Temperature

CONCLUSIONS

Without controllers, the sent outgas of the regasification terminal didn't meet the requirement of a power plant. The molar flow of gas deviates 14% from the set point. For gas temperature, if AAV operates for more than 4 hours, the sent out gas temperature will be below 2.5°C. The controller used in this simulation is PI type controller to control sent out gas at 6.53 MMSCFD with tuning parameter of Kc = 0.00638 and Ti = 0.00043 and digital on-off type controllers to control the unloading pump and switching between AAV when the temperature of sent out gas near 3°C. The maximum operating time for each AAV is 5 hours 15 minutes before it will be switched for defrosting and it is replaced with the other AAV. The controller systems installed can meet the specification of gas feed for the power plant with a flow rate of 6.53 MMSCFD, pressure in the range of 20-28 barg and temperature gas above 2.5°C.

ACKNOWLEDGMENTS

The authors are grateful DRPM UI for supporting this work financially under the Hibah Penugasan Publikasi Internasional Terindeks 9 (PIT 9) Universitas Indonesia, Contract Number: NKB-0081/UN2.R3.1/HKP.05.00/2019.

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