IOP Conf. Series: Materials Science and Engineering **134** (2016) 012027 doi:10.1088/1757-899X/134/1/012027

Regasification of liquefied natural gas and hydrogen

V G Tonkonog[1], A L Tukmakov[1], K M Muchitova[1], U A Agalakov[1], F Sh Serazetdinov[2] and B C Gromov[2]

[1]Kazan National Research Technical University of A. N. Tupolev-KAI, Russia
[2]OOO NPP «Aviagas-Coyus+», Russia

E-mail tukmakov@imm.knc.ru

Abstract. Liquefied natural gas and hydrogen gasification process is suggested, in which vapor phase is generated by the decrease of internal energy of the liquid. Methane and hydrogen gasification processes have been numerically modeled. Flow rates of the methane and hydrogen through choke channel were defined. A satisfactory match between the modeled and experimental data for liquid nitrogen has been acquired. Technical suitability of the suggested process is proved. Based on the initial parameters of the cryogenic fluid, the amount of vapor phase is 5-20 % of the flow rate.

Liquefied natural gas (LNG) and liquid hydrogen (LH) are cryogenic fuels that are widely used in aerospace and ground power engineering. Lately LNG usage is growing in many countries [1]. LNG-based technological processes include transportation, as well as storage and vaporization. In example, LNG or LH is usually stored in tanks as liquid, and then vaporized prior to utilizing it in a power plant. Same occurs in local gas supply: LNG/LH is supplied to consumer as liquid, and vaporized prior usage. As following, development of vaporization technologies is most perspective.

Cryogenic fluid regasification might be performed in multiple ways: energy in the form of heat or mechanical work could be brought to it from outside environment, or LNG/LH can be vaporized using its own internal energy, or these ways could be combined.

Heating LNG by heat exchangers is highly feasible if vapor phase consumption rate is constant. However, when consumption rate is unstable, vaporization technology based on heat exchangers is somewhat limited due to heat exchangers are highly inertial. In this paper technological process of vaporization based on internal energy loss is proposed. Process is protected by RF patent № 2347934.

Proposed technological process consists of: cryogenic fuel storage tank, vapor phase generating choke, gas-liquid separator. Process stages are following: saturated liquefied cryogenic fluid is stored in heat-insulated tank at temperature To and pressure p which is saturation pressure for To ($p = p_s(To)$). Fluid is supplied to choke, either moved by pump or by vapor cap expansion in the tank. At choke fluid flows with negative pressure gradient, so its internal energy decreases and some amount of vapor phase is generated, so single-phase flow is transformed in two-phase gas-liquid flow, in which liquid phase temperature is lower than initial To because of internal energy loss. Then two-phase flow is separated in gas-liquid separator, liquid is returned to the storage tank and vapor is supplied to consumer. Since generated vapor and residual liquid temperature is lower than To, returned liquid phase cools fluid stored in tank, therefore improving gasification efficiency and decreasing the necessity of vapor drainage from tank. Proposed process has good dynamics and is easily controlled by changing choke cross-section.

In order to provide an estimation for real characteristics of proposed process, vapor generation by Laval nozzle was numerically modeled. Laval nozzle was selected as a choke because it has most feasible vapor generating characteristics. Both single-dimensional and two-dimensional cases of thermally non-equilibrated two-phase flow have been numerically modeled.

Single-dimensional model is based on following assumptions: flow is adiabatic, vaporization occurs in metastable part of phase envelope, liquid phase is overheated and amount of overheat is set according to [2], vapor phase is saturated, vapor and liquid phases have equal velocities. System of equations was solved using Runge-Kutta algorithm. Solution algorithm includes critical condition, at which flow rate through choke aspires to critical flow rate $J \rightarrow J_{cr}$ and pressure gradient is negative along all the choke $dp/dz<0$.

Calculated vapor mass fraction generated during H2 and CH4 adiabatic expansion in the Laval nozzle are presented on figure 1. Vapor fraction calculated both for equilibrated isentropic flow and non-equilibrated flow allows to estimate range of vapor fraction dependant on flow non-equilibrium rate. Results of calculation of vapor generator capacity for critical flowrates of N2, CH4 and H2 from state of saturation dependant on reduced pressure π are presented on figure 2, as well as R.J. Simoneau [3] and our own experimental data.

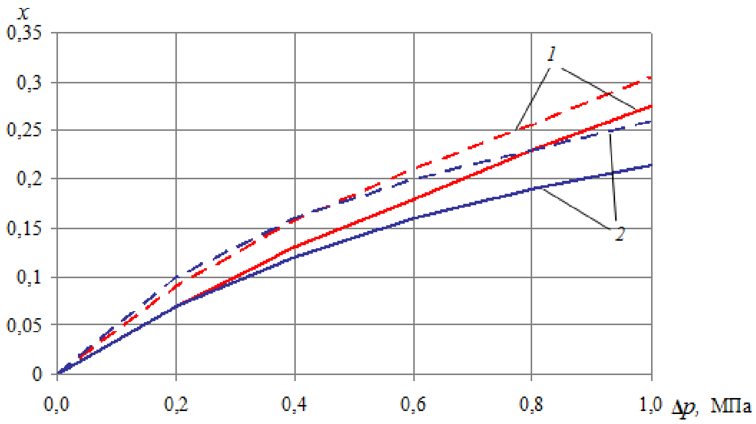

Figure 1. Vapor mass fraction, generated during adiabatic expansion in the choke channel. 1-normal H2, 2 – CH4.(----) – equilibrated process; (—) – non-equilibrated process

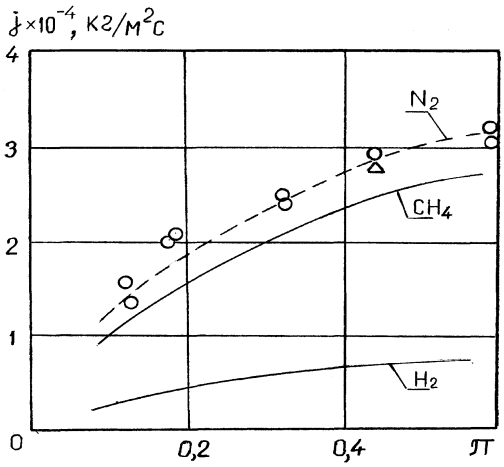

Figure 2. Specific flow rate through choke channel (Laval nozzle). ○-own experiment; Δ-R.J. Simoneau data [3].

Figure 2 shows satisfactory match between one-dimensional non-equilibrated model and experimental data, both our own and other researchers. Since fluid flow accompanied by its phase transitions has highly heterogeneous flow regime, for separator modules (which are important part of gasification process) development it is crucial to know local parameters of flow. Mainly it concerns local vapor fraction and flow regime. In order to solve this problem, the behavior of the two-phase flow in the separator for the two-dimensional case has been numerically modeled [4,5]. Te inversed problem has been solved – at given flow rate (calculated in one-dimensional case) separation characteristics have been simulated. Flow model and solution method is described in [6]. Figure 3 shows calculated vaporization front as well as vapor fraction distribution along the Laval nozzle for CH4 adiabatic flow.

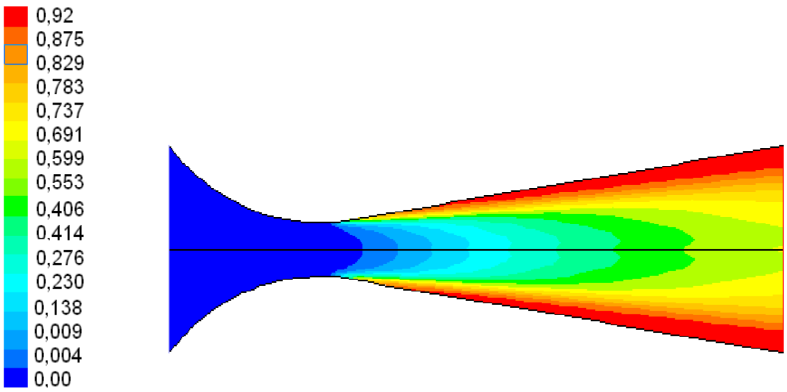

Figure 3. Vapor volume fraction for CH4 two phase adiabatic flow at initial parameters: p_o=0,5 MPa, T_o=130K

Cryogenic fluid regasification technological process is proposed. The H2 and CH4 gasification characteristics have been numerically simulated. Results might be used in cryogenic fluids gasification tools development.

Research was possible due to Ministry of Education of Russian Federation support as Federal Target Program (FTP). Grant contract № 14.577.21.0151. Topic: “Gasification process development and technology adaptation for power engineering”, Project unique ID is RFMEFI57714X0151.

References

[1] Vovk V S, Novikoff A I and Glagoleff A I etc 2009 *Liquid natural gas world industry and market: predictive modeling* M.: Gazprom expo
[2] Tonkonog V G and Gortyshov Yu F 2007 *Heat Transfer Research* **38** 661-668
[3] Simoneau J R 1975 Pressure Distribution in a Converging Diverging Nozzle During Two - Phase Choked Flow of Subcooled Nitrogen *In: ASME Non -Equilibrium Two -Phase Flow Symp* 37-45
[4] Saifutdinov A I, Saifutdinova A A, Kashapov N F and Fadeev S A 2016 *J. Phys.: Conf. Ser.* **669** 012045
[5] Saifutdinov A I, Fadeev S A, Saifutdinova A A and Kashapov N F 2015 *JETP Lett.* **102** 637–642
[6] Tonkonog V G and Bakoush A M 2006 *Izv. vuzov. Aviation tech*. **4** 47-49