Nuclear Engineering and Design 330 (2018) 516–523

Contents lists available at ScienceDirect

Nuclear Engineering and Design

journal homepage: www.elsevier.com/locate/nucengdes

Experimental investigation of gas lift pump in a lead-bismuth eutectic loop

Leitai Shi[a], Tan Bing[a], Chenglong Wang[a], Wenxi Tian[a], Suizheng Qiu[a], Junmei Wu[b], G.H. Su[a,*]

[a] Shannxi Key Lab. of Advanced Nuclear Energy and Technology, Xi'an Jiaotong University, PR China
[b] State Key Laboratory for Strength and Vibration of Mechanical Structures, Xi'an Jiaotong University, PR China

ARTICLE INFO

Keywords:
Gas lift pump
LBE
Two-phase flow
Average void friction

ABSTRACT

The gas lift pump has been used in the development of an Accelerator Driven System (ADS) nuclear reactor instead of mechanical pumps due to its simple mechanical structure. The two phase flow of Lead Bismuth eutectic (LBE)-inert gas in rising pipe could remarkably increase natural circulation capacity. This study aims to evaluate the performance of the gas lift pump and to conduct the relevant parametric study. As a result, the Natural Circulation Capability Loop (NCCL) test facility was designed and constructed. The height of the experimental loop is 4.5 m and the rising height is 3.5 m. The maximum temperature of the loop is 500 °C. The experiments about the gas lift pump in LBE were performed with risers of three different heights. The results showed that the LBE mass flow rate increases rapidly with an increase of argon flow rate when it is less than 300 NL/h. When the argon flow rate is larger than 300 NL/h, the growth of the LBE mass flow rate is reduced. The LBE mass flow rate increased process is accompanied by the transformation of the flow pattern. The variation trend of the LBE flow rate is consistent with the trend of the void friction in the riser. Under the same amount of argon gas injection, the LBE circulation ability increases as the height of the riser increased. Based on the experimental data and drift-flow model of Zuber and Findlay, a new correlation of the void fraction is obtained and the relative error between the calculated and the experimental value is within 30%. The purpose of this study is to reveal the enhancement mechanism of the natural circulation capacity of gas lift pump and to provide experimental data and model support for the design of ADS in China.

1. Introduction

The used fuel from pressurized water reactors contains many radionuclides, most of which decay rapidly. However, a large proportion of the wastes contained in used nuclear fuel is high-level radioactive wastes (HLW). The disposal of HLW has been a subject of continued discussion and public concern in many countries. Therefore, the accelerator-driven system (ADS) (Participants et al., 1978) has been proposed to transmute the HLW into shorter-lived radionuclides, making the management and eventual disposal of HLW easier and cheaper. ADS usually includes a proton accelerator, a spallation target and a sub-critical reactor. LBE is one of the best options for the spallation target and coolant of the reactor. Due to the strong thermal expansion, the LBE-cooled systems have significant natural circulation, which improves system security in postulated accidents (Borgohain et al., 2011; Li et al., 2015; Ma et al., 2007). And the gas lift pump has been applied to replace the mechanical pumps for the development of an ADS reactor (Cinotti and Gherardi, 2002).

The gas lift pump is a device for rising liquids in an ascension channel, by introducing the compressed gas into the channel. When the gas is injected into the ascension channel, the gas carries the liquid and moves upwards. Compared with the mechanical pumps, the advantage of the gas lift pump is that the mechanical structure is simple. Moreover, they can be used in radioactive and corrosive environment, and can be used in a variety of irregular shapes as well. In the past, the experimental study of the gas lift pump mainly concentrated on the gas and water, while the heavy metal and inert gas research are relatively few. Suzuki et al. (2003) investigated experimentally the bubble shapes in liquid metal and the average void fraction in a LBE-N_2 pool loop. They used the neutron radiography technique to visualize the bubble shapes. Comparing with the experimental results, they found that the original SIMMER-III can suitably represent high liquid-to-gas density ratio flows. And they developed a new procedure which the drag coefficient between bubbles and liquid can be selected according to bubble shape. Nishi et al. (2002) study the gas lift pump performance in a LBE loop with three different diameters risers. They obtained the relationship between the LBE mass flow and average void friction with the gas flow rate. And they found that the LBE flow rate calculated from the design method based on water/gas system with the drift flux model corresponds to the LBE/argon experimental results in the middle

* Corresponding author.
E-mail address: ghsu@mail.xjtu.edu.cn (G.H. Su).

https://doi.org/10.1016/j.nucengdes.2018.01.042
Received 31 May 2017; Received in revised form 12 January 2018; Accepted 24 January 2018

Nomenclature

P	pressure (Pa)
g	gravitational constant (m/s^2)
H	height (m)
j	superficial velocity (m/s)
u	phase velocity (m/s)

Greek symbols

ρ	density (kg/m^3)
α	void fraction
σ	surface tension (N/m)

Subscripts

DF	driving force
fric	friction
l	liquid phase
g	gas phase
acc	acceleration
grav	gravity
meas	measure
gj	between gas and liquid
acq	acquisition system
ins	instrument

Acronyms

LBE	lead bismuth eutectic
ADS	accelerator-driven system
HLW	high-level radioactive wastes
EM	electromagnetic

diameter and small diameter of riser. But in a large diameter riser, the method excessively evaluates the LBE flow rate. Benamati et al. (2007) conducted the gas lift pump experiments to investigate the possibility of achieving a stable circulation in a LBE pool facility named CIRCE. The results showed that when the argon flow rate greater than 1 NL/s, a steady flow of LBE will be reached. Moreover, Saito et al. (2005) used the neutron radiography and electrical conductivity probe to measure the LBE-argon two-phase flow. From the visualization of the two-phase flow, they found that the cap bubbles and elongated slug bubbles were dominant at a certain range of the superficial gas velocity and no stable Taylor bubbles were detected in their experiments.

For the theoretical study of LBE/inert gas two-phase flow, Satyamurthy et al. (1998) have developed a two-fluid vertical flow model about the high density liquid metals and suitable gas/vapor. This model consisted of gas momentum equation, combined momentum equation, one-dimensional continuity equations for gas and liquid metal along with the auxiliary equations. The calculated values have been compared against the experimental data. They found that the model agreed well with experimental data when the cross-sectional effects were neglected. Mikityuk et al. (2005) have developed a drift-flux model for heavy liquid metal/gas flow to calculate the void fraction by analyzing five sets of experimental data with different geometries, working fluids, void fraction and flow rates ranges. The calculated results of void fraction meet well with the experimental results. Zuo et al. (2013) have numerically simulated the rising behaviors of a single nitrogen bubble in LBE liquid metals by using two-dimensional moving particle semi-implicit (MPS) method. They studied the rising velocity, aspect ratio and bubble shape during ascending process of a single nitrogen bubble. The calculated results show that the bubble terminal velocity and aspect ratio increase with the liquid velocity increases. Tian et al. (2013) have used the steam lift pump in their code which is used to analyze the safety of a Pb-Bi-cooled direct contact boiling water fast reactor. In addition, a lot of work has been done about LBE faster reactor. Wang et al. (2013) have developed a sub-channel analysis code for the preliminary analysis in advanced lead bismuth fast reactor fuel. They have analyzed the lead bismuth fast reactor sub-channel characters by using this code.

In order to study the thermal-hydraulic characteristics of LBE in ADS, the Natural Circulation Capability Loop (NCCL) test facility was designed and constructed at Xi'an Jiaotong University in 2015 by the Nuclear Thermal-hydraulic Laboratory (NuTHeL). NCCL is a middle-scale experimental loop designed for investigating the natural circulation capacity, gas-lift pump enhancing circulation capacity and heat-transfer characteristic of LBE. The main purpose is to provide the corresponding experimental data and models support for the design of ADS in China. Although many experimental and theoretical studies on LBE/argon gas lift pump have been carried out. However, the effect of different riser height on the circulation capacity of gas lift pump has not been studied. In this paper, the circulation capability for different riser height and the distribution of void fraction along the riser were studied.

2. Experimental facility

NCCL is a high temperature experimental facility built to study the thermal-hydraulic characteristics of LBE which is considered as spallation target and coolants of ADS. One of the main studies of this loop is the gas-injection enhanced circulation capability of LBE. The facility mainly includes LBE loop, argon loop, electric heating system, data acquisition system, electromagnetic flowmeter (EMF) and EM flowmeter calibration system. The specific parameters of the NCCL are listed in Table 1. Fig. 1 shows the schematic of the experimental facility.

The LBE loop is mainly composed of melting tank, riser, gas-liquid separation chamber, EM flowmeter, EM flowmeter calibration tube, downcomer, electric heating system and measuring instrument. The melting tank is used for storing and melting LBE, heating the tank by electric heating wire, and heating power is 6 kW. During the experiment, the level of LBE is located in the center of the gas-liquid separation chamber, leaving enough space for the separation of LBE and argon gas. The EM flowmeter is designed to measure volume flow of the liquid LBE. The calibration tube is used to calibrate the EM flowmeter which equipped with five liquid level probes at different heights. In order to preheat and offset the heat losses, the entire LBE loop is wrapped around the electric heating wire. On the other hand, the LBE loop is wrapped with an insulating layer to reduce heat loss. All pipes and components of this loop contacted directly with LBE are produced by 316L stainless steel. The height of the experimental loop is 4.5 m and the rising height is 3.5 m. The maximum temperature of the loop is 500 °C. In order to prevent outer air from entering the experimental loop, the gas-liquid separation chamber connects with the atmosphere through a check valve.

Table 1
The specific parameters of the NCCL.

Characteristics	Parameters
Rising height	3.5 m
Width	1.13 m
Operating temperature	320 °C
Working pressure range	0.1–0.5 MPa
Piping	38 mm O.D. and 32 mm I.D.
Material	316L stainless steel
Working fluid	LBE and Argon gas
Preheating of piping	rope heater