Nordisk kernesikkerhedsforskning
Norrænar kjarnöryggisrannsóknir
Pohjoismainen ydinturvallisuustutkimus
Nordisk kjernesikkerhetsforskning
Nordisk kärnsäkerhetsforskning
Nordic nuclear safety research

NKS-199
ISBN 978-87-7893-266-2

PPOOLEX Experiments with a Modified Blowdown Pipe Outlet

Jani Laine, Markku Puustinen, Antti Räsänen
Lappeenranta University of Technology, Finland

August 2009

Abstract

This report summarizes the results of the experiments with a modified blowdown pipe outlet carried out with the PPOOLEX test facility designed and constructed at Lappeenranta University of Technology. Steam was blown into the dry well compartment and from there through a vertical DN200 blowdown pipe to the condensation pool. Four reference experiments with a straight pipe and ten with the Forsmark type collar were carried out. The main purpose of the experiment series was to study the effect of a blowdown pipe outlet collar design on loads caused by chugging phenomena (rapid condensation) while steam is discharged into the condensation pool.

The PPOOLEX test facility is a closed stainless steel vessel divided into two compartments, dry well and wet well. During the experiments the initial temperature level of the condensation pool water was either 20–25 or 50–55 C. The steam flow rate varied from 400 to 1200 g/s and the temperature of incoming steam from 142 to 185 C.

In the experiments with 20–25 C pool water, even 10 times higher pressure pulses were measured inside the blowdown pipe in the case of the straight pipe than with the collar. In this respect, the collar design worked as planned and removed the high pressure spikes from the blowdown pipe. Meanwhile, there seemed to be no suppressing effect on the loads due to the collar in the pool side in this temperature range. Registered loads in the pool were approximately in the same range (or even a little higher) with the collar as with the straight pipe.

In the experiments with 50–55 ºC pool water no high pressure pulses were measured inside the blowdown pipe either with the straight pipe or with the collar. In this case, more of the suppressing effect is probably due to the warmer pool water than due to the modified pipe outlet. It has been observed already in the earlier experiments with a straight pipe in the POOLEX and PPOOLEX facilities that warm pool water has a diminishing effect on water hammers and pressure loads inside the blowdown pipe.

However, warm water seems not to prevent pressure loads in the condensation pool. Even an order of magnitude higher loads were measured with the collar than without it at the blowdown pipe outlet (measurement P5). At least in the 50–55 ºC temperature range, the collar doesn't seem to work as planned. Instead, it looks like it can even magnify pressure loads in the condensation pool.

Key words

condensation pool, steam/air blowdown, blowdown pipe

NKS-199
ISBN 978-87-7893-266-2

Electronic report, August 2009

NKS Secretariat
NKS-776
P.O. Box 49
DK - 4000 Roskilde, Denmark

Phone +45 4677 4045
Fax +45 4677 4046
www.nks.org
e-mail nks@nks.org

Research Report
Lappeenranta University of Technology
Nuclear Safety Research Unit

CONDEX 2/2008

PPOOLEX EXPERIMENTS WITH A MODIFIED BLOWDOWN PIPE OUTLET

Jani Laine, Markku Puustinen, Antti Räsänen

Lappeenranta University of Technology
Department of Energy and Environmental Technology
Nuclear Safety Research Unit
P.O. Box 20, FIN-53851 LAPPEENRANTA, FINLAND
Phone +358 5 621 11

Lappeenranta, 29.5.2009

LAPPEENRANTA UNIVERSITY OF TECHNOLOGY

<table>
<tr><td colspan="2">Research organization and address
Lappeenranta University of Technology
Nuclear Safety Research Unit
P.O. Box 20
FIN-53851 LAPPEENRANTA, FINLAND
Project manager
Markku Puustinen</td><td colspan="2">Customer
VYR / SAFIR2010
NKS

Contact person
Eija-Karita Puska (SAFIR)
Patrick Isaksson (NKS)</td></tr>
<tr><td colspan="2">Project title and reference code
SAFIR2010-CONDEX
NKS-POOL</td><td>Report identification & Pages
CONDEX 2/2008
29 p. + app.8 p.</td><td>Date
29.5.2009</td></tr>
</table>

Report title and author(s)

PPOOLEX Experiments with a Modified Blowdown Pipe Outlet

Jani Laine, Markku Puustinen, Antti Räsänen

Summary

This report summarizes the results of the experiments with a modified blowdown pipe outlet carried out with the PPOOLEX test facility designed and constructed at Lappeenranta University of Technology. Steam was blown into the dry well compartment and from there through a vertical DN200 blowdown pipe to the condensation pool. Four reference experiments with a straight pipe and ten with the Forsmark type collar were carried out. The main purpose of the experiment series was to study the effect of a blowdown pipe outlet collar design on loads caused by chugging phenomena (rapid condensation) while steam is discharged into the condensation pool.

The PPOOLEX test facility is a closed stainless steel vessel divided into two compartments, dry well and wet well. During the experiments the initial temperature level of the condensation pool water was either 20–25 or 50–55 °C. The steam flow rate varied from 400 to 1200 g/s and the temperature of incoming steam from 142 to 185 °C.

In the experiments with 20–25 °C pool water, even 10 times higher pressure pulses were measured inside the blowdown pipe in the case of the straight pipe than with the collar. In this respect, the collar design worked as planned and removed the high pressure spikes from the blowdown pipe. Meanwhile, there seemed to be no suppressing effect on the loads due to the collar in the pool side in this temperature range. Registered loads in the pool were approximately in the same range (or even a little higher) with the collar as with the straight pipe.

In the experiments with 50–55 °C pool water no high pressure pulses were measured inside the blowdown pipe either with the straight pipe or with the collar. In this case, more of the suppressing effect is probably due to the warmer pool water than due to the modified pipe outlet. It has been observed already in the earlier experiments with a straight pipe in the POOLEX and PPOOLEX facilities that warm pool water has a diminishing effect on water hammers and pressure loads inside the blowdown pipe.

However, warm water seems not to prevent pressure loads in the condensation pool. Even an order of magnitude higher loads were measured with the collar than without it at the blowdown pipe outlet (measurement P5). At least in the 50–55 °C temperature range, the collar doesn't seem to work as planned. Instead, it looks like it can even magnify pressure loads in the condensation pool.

Distribution

E. Virtanen (STUK), N. Lahtinen (STUK), T. Toppila (Fortum), Heikki Kantee (Fortum), M. Lemmetty (TVO), J. Poikolainen (TVO), A. Hämäläinen (VTT), A. Daavittila (VTT), T. Siikonen (TKK), V. Kouhia (LTY), J. Aurela (KTM), H. Heimburger (STUK), E. K. Puska (VTT), V. Suolanen (VTT), T. Pättikangas (VTT), I. Karppinen (VTT), A. Timperi (VTT), P. Smeekes (TVO), R. Kyrki-Rajamäki (LTY), V. Tanskanen (LTY)), J. Vihavainen (LTY), M. Pikkarainen (LTY), A. Jordan (LTY), T. Merisaari (LTY), A. Rantakaulio (LTY), H. Suikkanen (LTY), P. Isaksson (Vattenfall), P. Kudinov (KTH)

Principal author or Project manager	**Reviewed by**
Jani Laine, Research Scientist	Vesa Riikonen, Senior Research Scientist
Approved by	**Availability statement**
Heikki Purhonen, Senior Research Scientist	SAFIR2010 limitations

PREFACE

Condensation pool studies started in Nuclear Safety Research Unit at Lappeenranta University of Technology (LUT) in 2001 within the Finnish Research Programme on Nuclear Power Plant Safety (FINNUS). The experiments were designed to correspond to the conditions in the Finnish boiling water reactors (BWR) and the experiment programme was partially funded by Teollisuuden Voima Oy (TVO). Studies continued in 2003 within the Condensation Pool Experiments (POOLEX) project as a part of the Safety of Nuclear Power Plants - Finnish National Research Programme (SAFIR). The studies were funded by the State Nuclear Waste Management Fund (VYR) and by the Nordic Nuclear Safety Research (NKS).

In these research projects, the formation, size and distribution of non-condensable gas and steam bubbles in the condensation pool was studied with an open scaled down pool test facility. Also the effect of non-condensable gas on the performance of an emergency core cooling system (ECCS) pump was examined. The experiments were modelled with computational fluid dynamics (CFD) and structural analysis codes at VTT.

A new research project called Condensation Experiments with PPOOLEX Facility (CONDEX) started in 2007 within the SAFIR2010 - The Finnish Research Programme on Nuclear Power Plant Safety 2007–2010. The CONDEX project focuses on different containment issues and continues further the work done in this area within the FINNUS and SAFIR programs. For the new experiments, a closed test facility modelling the dry well and wet well compartments of BWR containment was designed and constructed. The main objective of the CONDEX project is to increase the understanding of different phenomena inside the containment during a postulated main steam line break (MSLB) accident. The studies are funded by the VYR, NKS and Nordic Nuclear Reactor Thermal-Hydraulics Network (NORTHNET).

CONTENTS

APPENDIXES:

NOMENCLATURE

p	pressure
Q	volumetric flow rate
q_m	mass flow rate
T	temperature

Greek symbols

Δ	change
ε	strain

Abbreviations

BWR	boiling water reactor
CFD	computational fluid dynamics
CONDEX	Condensation experiments
DCC	direct contact condensation
ECCS	emergency core cooling system
LOCA	loss-of-coolant accident
LUT	Lappeenranta University of Technology
MOV	QuickTime
MSLB	main steam line break
NKS	Nordic nuclear safety research
PACTEL	parallel channel test loop
POOLEX	condensation pool experiments project
PPOOLEX	pressurized condensation pool experiments project
PWR	pressurized water reactor
SAFIR	Safety of Nuclear Power Plants - Finnish National Research Programme
SD	secure digital
SLR	steam line rupture
SRV	safety/relief valve
TVO	Teollisuuden Voima Oyj
VTT	Technical Research Centre of Finland
VYR	State Nuclear Waste Management Fund
VVER	Vodo Vodjanyi Energetitseskij Reaktor

1 INTRODUCTION

During a postulated main steam line break accident inside the containment a large amount of non-condensable (nitrogen) and condensable (steam) gas is blown from the upper dry well to the condensation pool through the blowdown pipes in the Olkiluoto type BWR. The wet well pool serves as the major heat sink for condensation of steam. Figure 1 shows the schematic of the Olkiluoto type BWR containment.

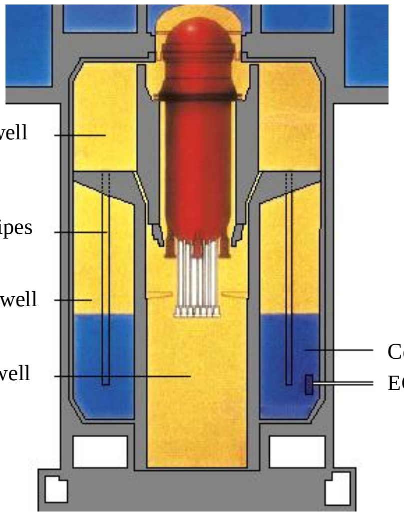


Figure 1. Schematic of the Olkiluoto type BWR containment.

The main objective of the CONDEX project is to improve understanding and increase fidelity in quantification of different phenomena inside the dry and wet well compartments of BWR containment during steam discharge. These phenomena could be connected, for example, to bubble dynamics issues, thermal stratification and mixing, wall condensation, direct contact condensation (DCC) and interaction of parallel blowdown pipes. Steam bubbles interact with pool water by heat transfer, condensation and momentum exchange via buoyancy and drag forces. Pressure oscillations due to rapid condensation can occur frequently.

To achieve the project objectives, a combined experimental/analytical/computational study programme is being carried out. Experimental part at LUT is responsible for the development of a database on condensation pool dynamics and heat transfer at well controlled conditions. Analytical/computational part at VTT, KTH and LUT use the developed experimental database for the improvement and validation of models and numerical methods including CFD and system codes. Also analytical support is provided for the experimental part by pre- and post-calculations of the experiments. Furthermore, the (one-directional or bi-directional) coupling of CFD and structural analysis codes in solving fluid-structure interactions can be facilitated with the aid of load measurements of the steam blowdown experiments. Some of the bubble dynamics models are applicable also outside the BWR scenarios, e.g. for the quench tank operation in the pressurizer vent line of a Pressurized Water Reactor (PWR), for the bubble condenser in a VVER-440/V213 reactor system, or in case of a submerged steam generator pipe break.

In 2006, a new test facility, called PPOOLEX, related to BWR containment studies was designed and constructed by Nuclear Safety Research Unit at LUT. It models both the dry and wet well (condensation pool) compartments of the containment and withstands prototypical system pressures. Experience gained with the operation of the preceding open POOLEX facility was extensively utilized in the design and construction process of the new facility.

Experiments with the new PPOOLEX facility started in 2007 by running a series of characterizing tests [1]. They focused on observing the general behaviour of the facility, on testing instrumentation and the proper operation of the automation, control and safety systems. The next five experiments (SLR series) focused on the initial phase of a postulated MSLB accident inside the containment [2]. Air was used as the flowing substance in these experiments. The research program continued in 2008 with a series of thermal stratification and mixing experiments [3]. Stratification in the water volume of the wet well during small steam discharge was of special interest. In December 2008 and January 2009 a test series focusing on steam condensation in the dry well compartment was carried out [4].

The research programme continued in April and May 2009 with 14 experiments (COL series) studying the effect of a blowdown pipe outlet collar design on loads caused by chugging phenomena. In this report, the results of these experiments are presented. First, chapter two gives a short description of the test facility and its measurements as well as of the data acquisition system used. The test programme of the COL experiment series is introduced in chapter three. The test results are presented and shortly discussed in chapter four. Chapter five summarizes the findings of the experiment series.

2 PPOOLEX TEST FACILITY

Condensation studies at LUT started with an open pool test facility (POOLEX) modelling the suppression pool of the BWR containment. During the years 2002-2006, the facility had several modifications and enhancements as well as improvements of instrumentation before it was replaced with a more versatile PPOOLEX facility in the end of 2006. The PPOOLEX facility is described in more detail in reference [5]. However, the main features of the facility and its instrumentation are introduced below. Some test facility photographs are shown in Appendix 2.

2.1 TEST VESSEL

The PPOOLEX facility consists of a wet well compartment (condensation pool), dry well compartment, inlet plenum and air/steam line piping. An intermediate floor separates the compartments from each other but a route for gas/steam flow from the dry well to the wet well is created by a vertical blowdown pipe attached underneath the floor.

The main component of the facility is the ~31 m^3 cylindrical test vessel, 7.45 m in height and 2.4 m in diameter. The vessel is constructed from three separate plate cylinder segments and from two dome segments. The test facility is able to withstand considerable structural loads caused by rapid condensation of steam. The vessel sections modelling dry well and wet well are volumetrically scaled according to the compartment volumes of the Olkiluoto containment buildings (ratio approximately 1:320). The DN200 (∅ 219.1 x 2.5 mm) blowdown pipe is positioned inside the pool in a non-axisymmetric location, i.e. 300 mm away from the centre of the condensation pool. Horizontal piping (inlet plenum) for injection of gas and steam penetrates through the side wall of the dry well compartment. The length of the inlet plenum is 2.0 m and the inner diameter 214.1 mm. There are several windows for visual observation in the walls of both compartments. A DN100 (∅ 114.3 x 2.5 mm) drain pipe with a manual valve is connected to the bottom of the vessel. A relief valve connection is mounted on the vessel head. The large removable vessel head and a man hole (DN500) in the wet well compartment wall provide access to the interior of the vessel for maintenance and modifications of internals and instrumentation. The test vessel is not thermally insulated. A sketch of the test vessel is presented in Figure 2. Table 1 lists the main dimensions of the test facility compared to the conditions in the Olkiluoto plant.

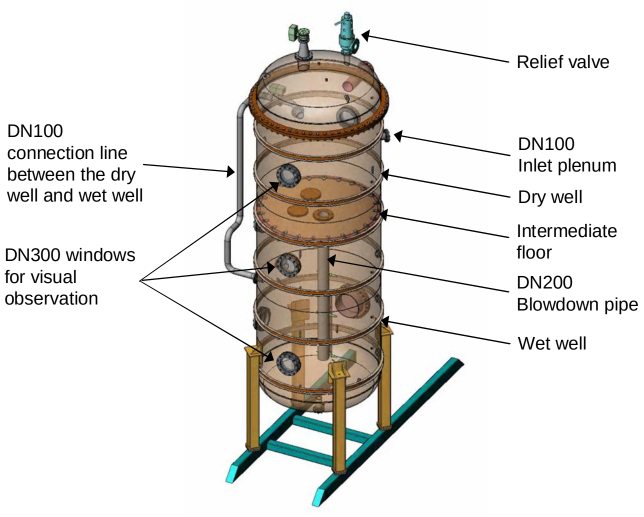


Figure 2. PPOOLEX test vessel.

Table 1. Test facility vs. Olkiluoto 1 and 2 BWRs.

	POOLEX test facility	Olkiluoto 1 and 2
Number of blowdown pipes	1	16
Inner diameter of the blowdown pipe [mm]	214.1	600
Suppression pool cross-sectional area [m^2]	4.45	287.5
Dry well volume [m^3]	13.3	4350
Wet well volume [m^3]	17.8	5725
Nominal water volume in the suppression pool [m^3]	8.38*	2700
Nominal water level in the suppression pool [m]	2.14*	9.5
Pipes submerged [m]	1.05	6.5
A_{pipes}/A_{pool}x100%	0.8**	1.6

* Water volume and level can be chosen according to the experiment type in question. The values listed in the table are based on the ratio of nominal water and gas volumes in the plant.
** With one blowdown pipe.

2.2 PIPING

In the plant, there are vacuum breakers between the dry and wet well compartments in order to keep the pressure in wet well in all possible accident situations less than 0.05 MPa above the dry well pressure. In the PPOOLEX facility, the pressure difference between the compartments is controlled via a connection line (Ø 114.3 x 2.5 mm) from the wet well gas space to the dry well. A remotely operated valve in the line can be programmed to open with a desired pressure difference according to test specifications. However, the pressure difference across the floor between the compartments should not exceed the design value of 0.2 MPa.

Steam needed in the experiments is produced with the nearby PACTEL [6] test facility, which has a core section of 1 MW heating power and three horizontal steam generators. Steam is led through a thermally insulated steam line, made of sections of standard DN80 (Ø88.9x3.2) and

DN50 (Ø60.3x3.9) pipes, from the PACTEL steam generators towards the test vessel. The steam line is connected to the DN200 inlet plenum with a 0.47 m long cone section. Accumulators connected to the compressed air network of the lab can be used for providing non-condensable gas injection. A schematic illustration of the air and steam line piping is presented in Figure 3.

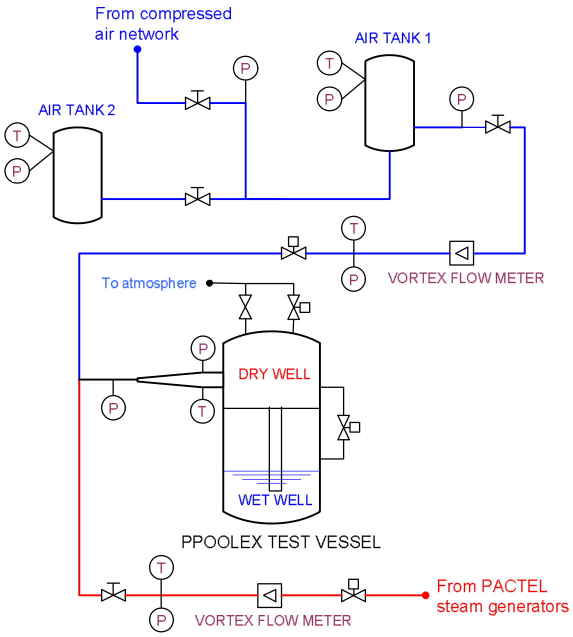


Figure 3. Arrangement of air and steam supply in the PPOOLEX facility.

2.3 COLLAR

A stainless steel collar was manufactured and attached to the outlet of the blowdown pipe, Figure 4. Dimensions of the collar were scaled down with the ratio of the blowdown pipe diameters of the PPOOLEX facility and reference plant (Forsmark). System 316 blowdown pipes at Forsmark units 1 and 2 in Sweden have collars attached to them. A detailed drawing of the collar is shown in Appendix 1. Because the collar was attached without shortening the original pipe length, the outlet of the collar pipe was about 40 mm lower than the outlet of the straight blowdown pipe.

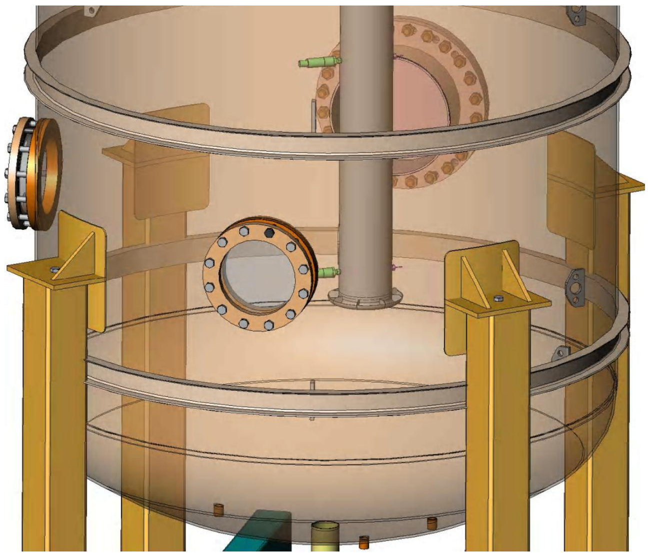


Figure 4. Collar attached to the blowdown pipe outlet in the PPOOLEX facility.

2.4 MEASUREMENT INSTRUMENTATION

Investigation of the steam/gas injection phenomenon requires high-grade measuring techniques. For example, to estimate the loads on pool structures by condensation pressure oscillations the frequency and amplitude of the oscillations have to be measured. Experience on the use of suitable instrumentation and visualization equipment was achieved already during the preceding research projects dealing with condensation pool issues.

The applied instrumentation depends on the experiments in question. Normally, the test facility is equipped with several thermocouples (T) for measuring air/steam and pool water temperatures and with pressure transducers (P) for observing pressure behaviour in the dry well compartment, inside the blowdown pipe, at the condensation pool bottom and in the gas phase of the wet well compartment. Steam and air flow rates are measured with vortex flow meters (F) in the steam and air lines. Additional instrumentation includes, for example, strain gauges (S) on the pool outer wall and valve position sensors. Strains are measured both in circumferential and axial direction.

Some of the measurements used in the earlier series were disconnected during the collar experiments to make room for increased recording frequency. A list of different types of measurements of the PPOOLEX facility during the COL experiments is presented in Table 2. The figures in Appendix 1 show the exact locations of the measurements and the table in Appendix 1 lists the identification codes and error estimations of the measurements. The error estimations are calculated on the basis of variance analysis. The results agree with normal distributed data with 95 % confidence interval.

Table 2. Instrumentation of the PPOOLEX test facility.

Quantity measured		No.	Range	Accuracy
Pressure	Dry well	1	0–6 bar	0.06 bar
	Wet well	5	0–6/0–10 bar	0.4/0.5 bar
	Blowdown pipe	3	0–10 bar	0.7 bar
	Inlet plenum	1	0–6 bar	0.06 bar
	Steam line	1	1–51	0.5 bar
	Air line	2	0–6/1–11 bar	0.06/0.1 bar
	Air tanks 1&2	2	0–16/0–11 bar	0.15/0.11 bar
Temperature	Dry well	5	-40–200 °C	±3.2 °C
	Wet well gas space	3	0–250 °C	±2.0 °C
	Wet well water volume	2	0–250 °C	±2.0 °C
	Blowdown pipe	6	0–250 °C	±2.0 °C
	Inlet plenum	1	-40–200 °C	±3.2 °C
	Steam line	2	0–400 °C	±3.6 °C
	Air line	1	-20–100 °C	±2.8 °C
	Air tanks 1&2	2	-20–100/200 °C	±2.8/3.1 °C
	Structures	7	0–200 °C	±2.6 °C
Mass flow rate	Steam line	1	0–285 l/s	±4.9 l/s
	Gas line	1	0–575 m^3/h	±18 g/s
Water level in the wet well		1	0–30000 Pa	0.06/0.03 m
Pressure difference across the floor		1	-499–505 kPa	± 9.7 kPa
Loads on structures		4	N/A	N/A
Vertical movement of the pool bottom		1	N/A	N/A
Vertical acceleration of the pool bottom		1	N/A	N/A

2.5 CCTV SYSTEM

In the experiments with the modified blowdown pipe outlet, standard video cameras, digital videocassette recorders and a quad processor were used for visual observation of the test vessel interior. With a digital colour quad processor it is possible to divide the TV screen into four parts and look at the view of four cameras on the same screen, Figure 5.

For more accurate observation of air/steam bubbles at the blowdown pipe outlet, a Casio Exilim EX-F1 digital camera [7] was used. The camera is capable of recording high-speed videos. The high-speed recordings are at first stored to the Secure Digital (SD) memory card in the camera in the QuickTime (.MOV) file format. From there they can be transferred to the PC hard disk via USB-cable. The camera is furnished with 2 GB SD memory card. The camera can achieve 1 200 frames/second (fps) recording speed with available 336x96 pixels resolution. During the experiments a recording speed of 300 fps with available resolution of 512x384 was used. Table 3 shows resolution/speed/recording time combinations that can be attained with the camera.

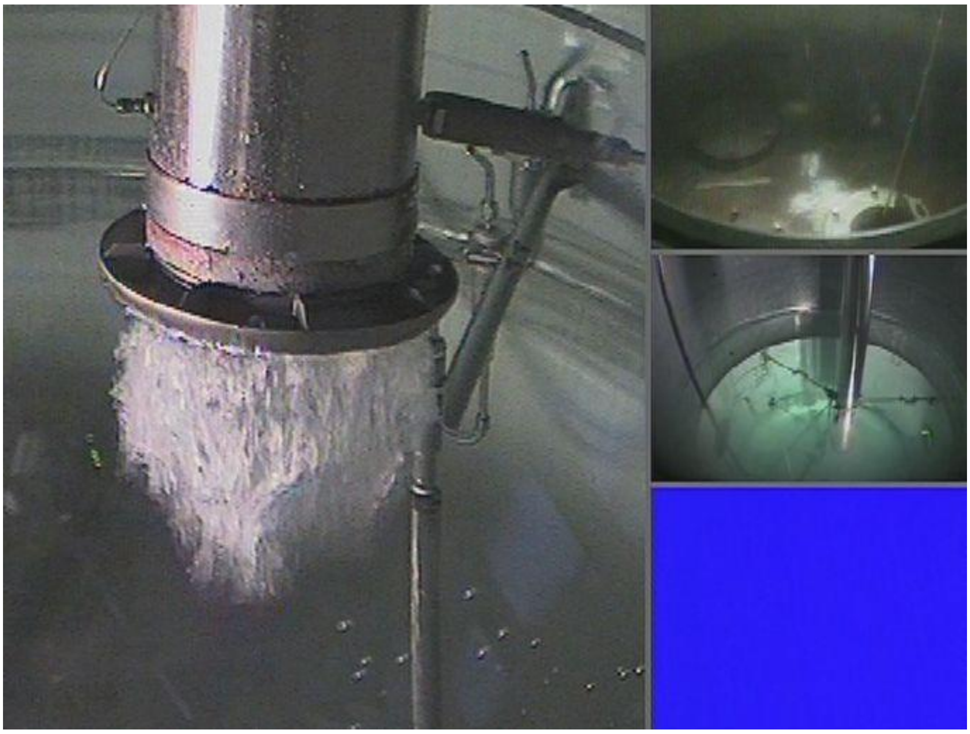


Figure 5. Typical camera views from the beginning of the COL experiments.

Table 3. Available resolution, recording speed and time combinations of the Casio Exilim EX-F1 digital camera.

Resolution [pixels]	Recording speed [fps]	Max recording time with 2 GB SD memory card [min, s]
336x96	1 200	14 min 36 s
432x192	600	14 min 38 s
512x384	300	14 min 38 s

2.6 DATA ACQUISITION

National Instruments PCI-PXI-SCXI PC-driven measurement system is used for data acquisition. The system enables high-speed multi-channel measurements. The maximum number of measurement channels is 96 with additional eight channels for strain gauge measurements. The maximum recording speed depends on the number of measurements and is in the region of three hundred thousand samples per second. Measurement software is LabView 8.6. The data acquisition system is discussed in more detail in reference [8].

National Instruments FieldPoint software is used for monitoring and recording the essential measurements of the PACTEL facility producing the steam. Both data acquisition systems measure signals as volts. After the experiments, the voltage readings are converted to engineering units with conversion software.

The used data recording frequency of LabView was 10 kHz (1 kHz in COL-06, COL-08 and COL-10). For the temperature measurements the data recording frequency was 100 Hz (20 Hz in COL-06, COL-08 and COL-10). The temperature measurements are therefore averaged of 100 or 50 measured points. The rest of the measurements (for example temperature, pressure and flow rate in the steam line) were recorded by FieldPoint software with the frequency of 0.67 Hz.

A separate measurement channel is used for the steam line valve position information. Approximately 3.6 V means that the valve is fully open, and 1.1 V that it is fully closed. Voltage under 1.1 V means the valve is opening. Both FieldPoint and LabView record the channel.

3 TEST PROGRAMME

The test programme in April and May 2009 consisted of 14 experiments (labeled from COL-01 to COL-14). Experiments focused on the effect of a blowdown pipe outlet collar design on loads caused by chugging phenomena. The experiments were carried out by using the DN200 blowdown pipe. Steam generators of the nearby PACTEL facility acted as a steam source.

Before each experiment the condensation pool was filled with isothermal water (temperature 20, 25, 50 or 55 °C) to the level of 2.14 m i.e. the blowdown pipe outlet was submerged by 1.05 m. This air/water distribution corresponds roughly to the scaled gas and liquid volumes in the containment of the reference plant. The steam source initial pressure was either 0.55 or 1.5 MPa. Between individual tests the test vessel was shortly ventilated with compressed air to dry the wall surfaces and to clear the viewing windows.

Initially, the dry well compartment was filled with air at atmospheric pressure. After the correct initial pressure level in the steam generators had been reached the remote-controlled shut-off valve in the steam line was opened. As a result, the dry well compartment was filled with steam that mixed there with the initial air content. Pressure build-up in the dry well then pushed water in the blowdown pipe downwards and after a while the pipe cleared and flow into the wet well compartment began. First, the flow was almost pure air and condensation at the pipe outlet was very light. As the fraction of steam among the flow increased the condensation phenomenon intensified. Chugging region of the condensation mode map was reached when the flow had decreased enough to let the steam/water interface periodically enter the blowdown pipe. From each experiment only a part of the chugging period was recorded with the high frequency measurement system to avoid too excessive amount of data.

Experiments COL-01…COL-04 were executed without and COL-05…COL-14 with the collar. During the test series some problems were met with the attachment of the collar and pressure measurements. During the first experiments with the collar (COL-05 and COL-06) it was noticed that the attachment between the blowdown pipe and the collar leaked. The attachment was modified before COL-07. During COL-02 and COL-06…COL-10 the measurement range of pressure transducer P5 (installed close the blowdown pipe outlet) was exceeded. The measurement range was raised from approximately 6 bar to 12.5 bar and all four experiment with the collar were repeated (COL-11…COL-14). However, the measurement range was still slightly exceeded during COL-12. Table 4 shows the main parameters of the COL experiments.

Table 4. Initial parameter values of the COL experiments.

Experiment	Steam source pressure [MPa]	Initial pool water level [m]	Initial pool water temperature [°C]	Comments
COL-01	0.55	2.14	20	X2102 not installed
COL-02	1.5	2.14	25	X2102 not installed, measurement range of P5 was exceeded
COL-03	0.55	2.14	50	X2102 not installed
COL-04	1.5	2.14	55	X2102 not installed
COL-05	0.55	2.14	20	Connection between the blowdown pipe and collar leaked, T2108 broken
COL-06	1.5	2.14	25	Connection between the pipe and collar leaked, T2108 broken, LabView 1 kHz
COL-07	0.55	2.14	20	Measurement range of P5 was exceeded
COL-08	1.5	2.14	25	Measurement range of P5 was exceeded, LabView 1 kHz
COL-09	0.55	2.14	50	Measurement range of P5 was exceeded
COL-10	1.5	2.14	55	Measurement range of P5 was exceeded, LabView 1 kHz
COL-11	0.55	2.14	20	-
COL-12	1.5	2.14	25	Measurement range of P5 was exceeded
COL-13	0.55	2.14	50	-
COL-14	1.5	2.14	55	-

4 ANALYSIS OF THE EXPERIMENTS

The following chapters give a more detailed description of the experiment program and present the observed phenomena. Table 5 summarizes the values of the main parameters during the whole COL experiment series. However, further analysis is done only with the experiments COL-01…COL-04 and COL-11…COL-14 i.e. the experiments where problems with the leaking collar attachment or with the too narrow measurement range were encountered are excluded.

Table 5. Main parameters during COL experiments.

Test	Initial pressure of steam generator [MPa]	Steam flow rate[1] [g/s]	Temperature of incoming steam[2] [°C]	Collar in use [Yes/ No]	Δp_{max} in the DN200 pipe[3] [kPa]	Δp_{max} in the pool[4] [kPa]	Δp_{max} at the pool bottom[5] [kPa]	$\Delta\varepsilon_{max}$[6] [μS]	Pool bottom vertical $\lvert a \rvert_{max.}$ [m/s²]	Pool bottom vertical Δs_{max} [mm]
COL-01	0.55	437…432	144	No	1600 (P1) 200 (P2)	270 (P5) 110 (P7) 80 (P8)	100	50	250	2.9
COL-02	1.5	595…560	161…159	No	390 90	>300[7] 80 60	70	35	180	0.8
COL-03	0.55	426…419	143	No	100 50	70 30 20	20	15	60	0.3
COL-04	1.5	627…543	163…160	No	50 20	40 20 10	20	5	20	0.5
COL-05	0.55	428…418	143	Yes	960 140	>300[7] 130 70	120	60	280	2.3
COL-06	1.5	595…507	163…159	Yes	330 270	>300[7] 100 60	100	40	200	1.4
COL-07	0.55	422…410	143	Yes	80 90	>300[7] 50 30	50	25	120	0.8
COL-08	1.5	595…507	163…159	Yes	180 210	>300[7] 140 70	100	45	>230	2.3
COL-09	0.55	421…411	143	Yes	300 210	>3007 100 50	90	50	280	2.4
COL-10	1.5	628…542	164…160	Yes	210 100	>3007 80 30	100	25	130	1.1
COL-11	0.55	405…410	142	Yes	150 120	410 90 70	70	40	220	1.5
COL-12	1.5	576…507	162…159	Yes	230 100	>1000[7] 200 70	120	35	210	1.4
COL-13	0.55	396…404	143	Yes	100 70	350 40 60	50	30	200	0.6
COL-14	1.5	628…542	165…161	Yes	180 160	470 170 50	80	25	170	1.2

[1] Steam mass flow rate was calculated on the basis of volumetric flow rate (measured by F2100) and density of steam, which was determined on the basis of the steam pressure measurement (measured by P2100) by assuming saturated steam flow.

[2] Measured by thermocouple T2102.

[3] Measured by pressure transducers P1 and P2.

[4] Measured by pressure transducers P5, P7 and P8.

[5] Measured by pressure transducer P6.

[6] Measured by strain gauge S4.

[7] Measurement range of pressure transducer P5 was exceeded.

4.1 EXPERIMENTS WITH INITIAL 20 °C POOL WATER

In experiments COL-01 and COL-11, the initial pressure of the steam source was 0.55 MPa and the initial temperature of pool water 20 °C. The same initial pressure of the steam source resulted to roughly similar flow rate behavior in both experiments, Figure 6. Also the pressure behavior in the dry and wet well was similar during the experiments. COL-01 was executed with the straight blowdown pipe and COL-11 with the collar.

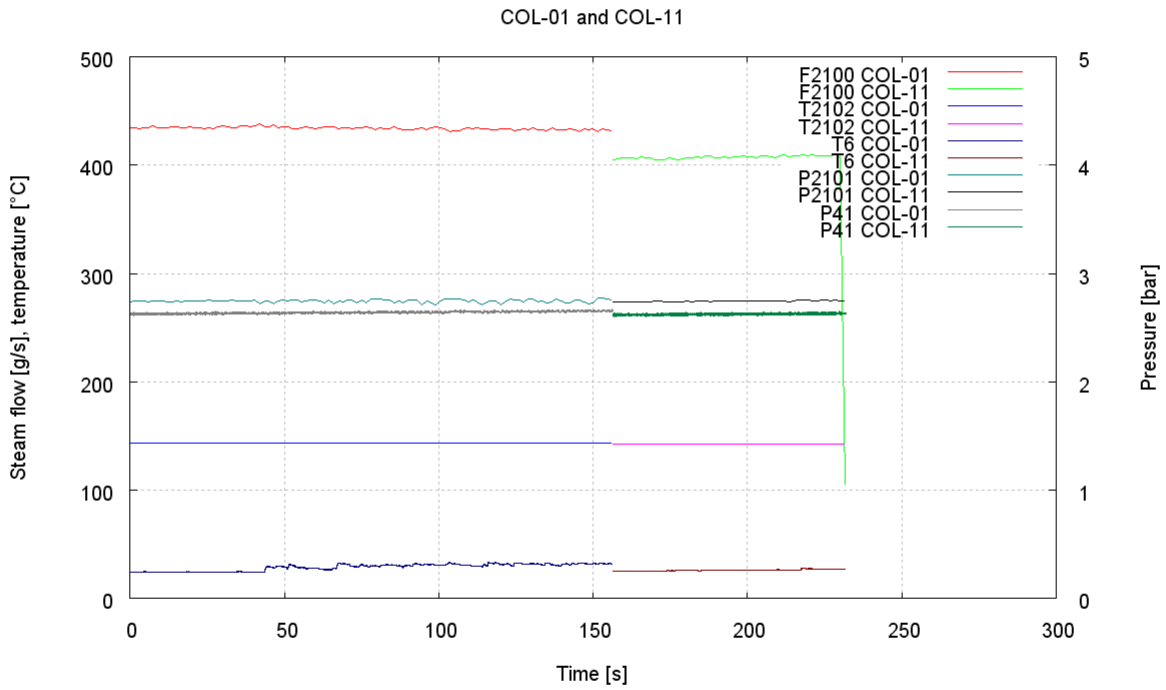


Figure 6. Flow rate (F2100), temperature of incoming steam (T2102) and pool water (T6) and pressure in the dry well (P2101) and wet well (P41) in COL-01 and COL-11 plotted in same figure. (Note that the actual timescale is discontinuous between the experiments in all figures.)

Chugging phenomenon was the dominating condensation mode in both experiments during the recorded interval. Because of rather low pool water temperature (approximately 20 °C) steam condensed mainly within the blowdown pipe and only quite small size steam bubbles formed at the blowdown pipe outlet. As a result of this high pressure pulses were registered inside the blowdown pipe in COL-01 when steam bubbles collapsed rapidly at the pipe outlet and water hammers developed and propagated inside the pipe. The maximum registered pressure pulse inside the blowdown pipe was 1.6 MPa, Figure 7. During the recorded interval of the test steam-water interface moved frequently up and down inside the blowdown pipe, Figure 8. This is characteristic for chugging phenomenon.

In COL-11, the general behavior was evidently different. No high pressure pulses (max. 150 kPa) were registered inside the blowdown pipe and the steam-water interface did not move as strongly inside the blowdown pipe as in COL-01. It seems that the collar design slows down water ingress into the pipe after the collapse of steam bubbles at the pipe outlet. Meanwhile, loads registered in the pool (pressure pulses, strains and vertical acceleration of the pool bottom) don’t indicate significant differences between COL-01 than COL-11, Figure 9…Figure 14. However, the effect of the collar cannot be concluded exactly because the blowdown pipe outlet was 40 mm lower (and closer for example to sensor P5) in COL-11 than in COL-01.

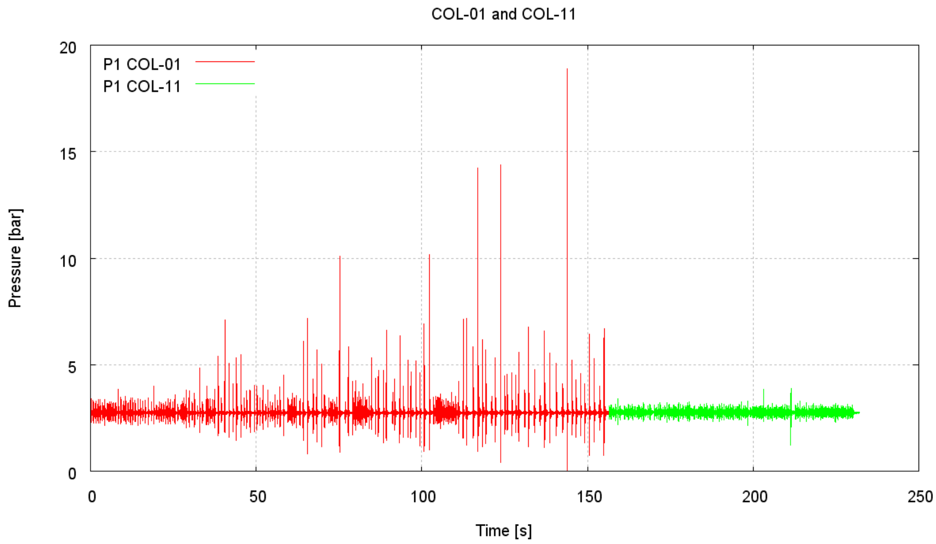


Figure 7. Pressure P1 in COL-01 and COL-11 plotted in the same figure.

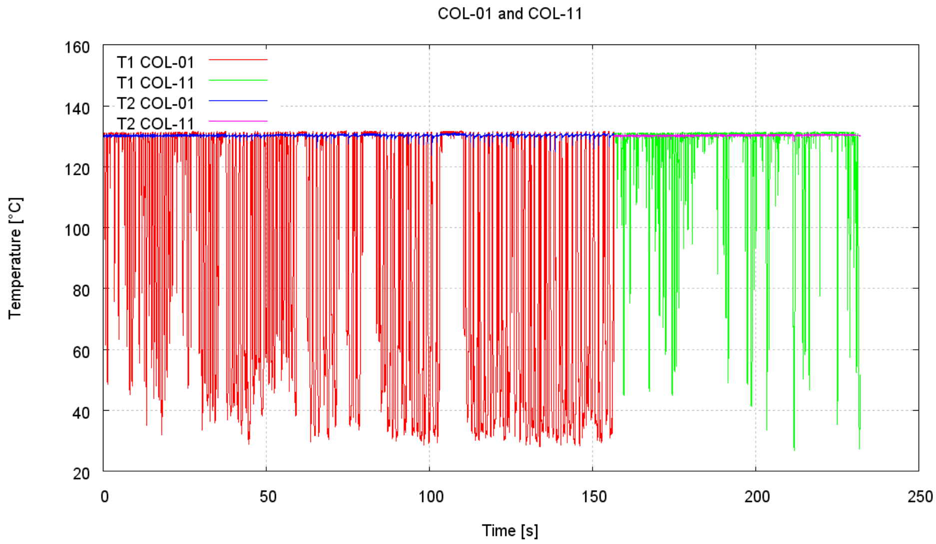


Figure 8. Temperatures T1 and T2 in COL-01 and COL-11 plotted in the same figure.

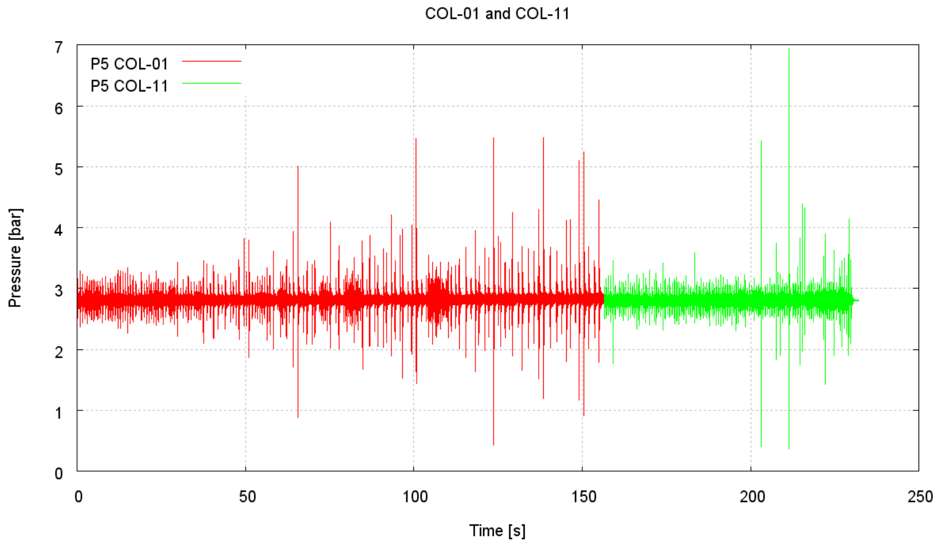


Figure 9. Pressure P5 in COL-01 and COL-11 plotted in the same figure.

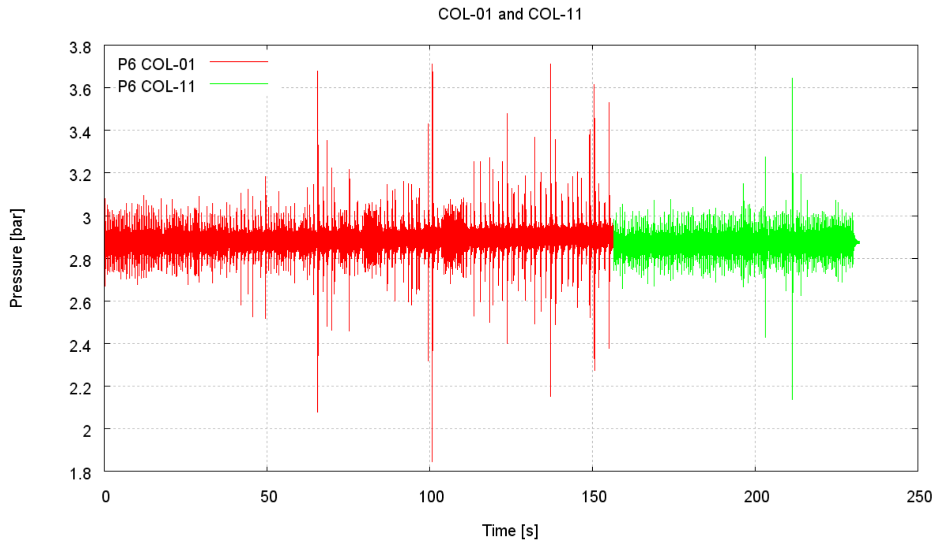


Figure 10. Pressure P6 in COL-01 and COL-11 plotted in the same figure.

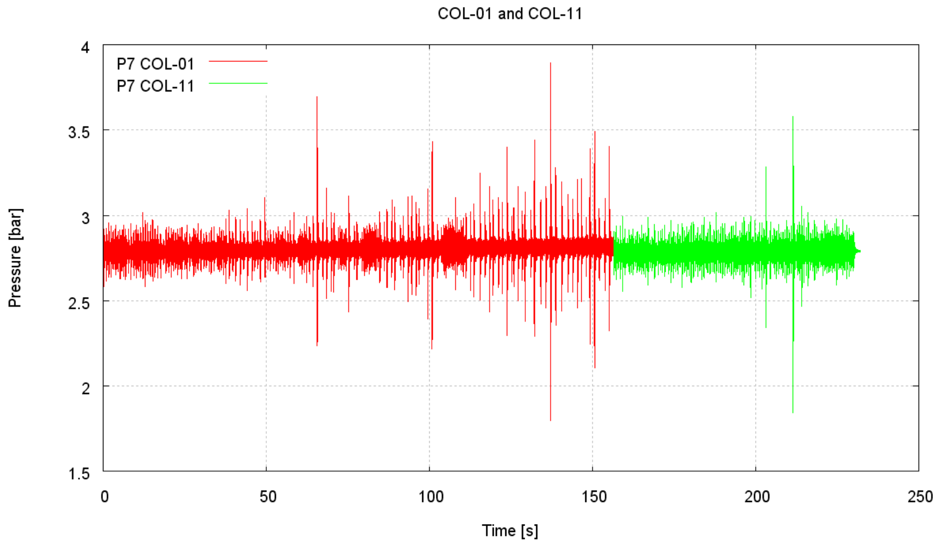


Figure 11. Pressure P7 in COL-01 and COL-11 plotted in the same figure.

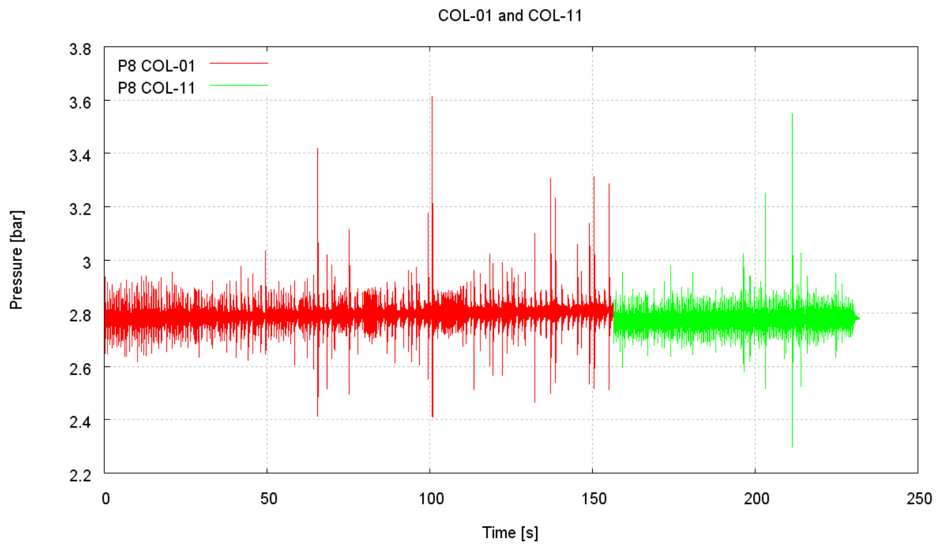


Figure 12. Pressure P8 in COL-01 and COL-11 plotted in the same figure.

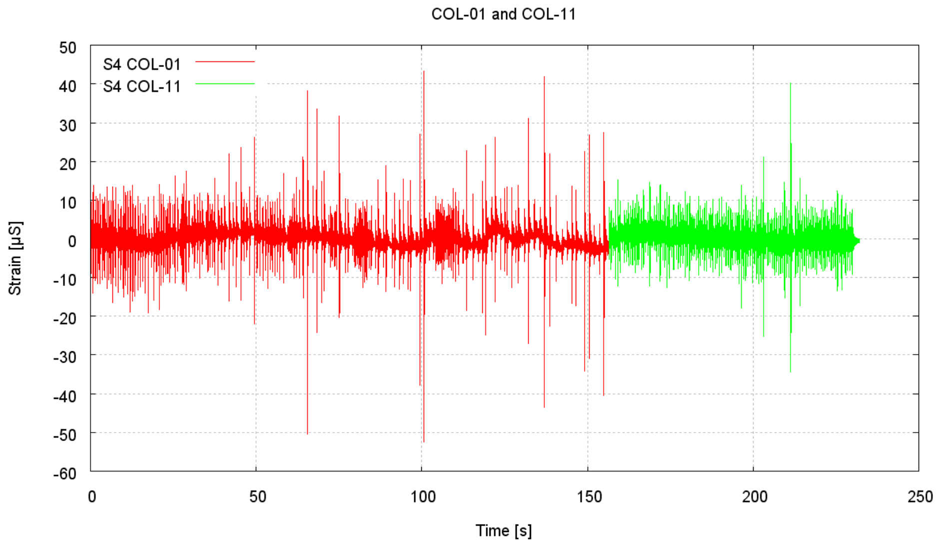


Figure 13. Strain S4 in COL-01 and COL-11 plotted in the same figure.

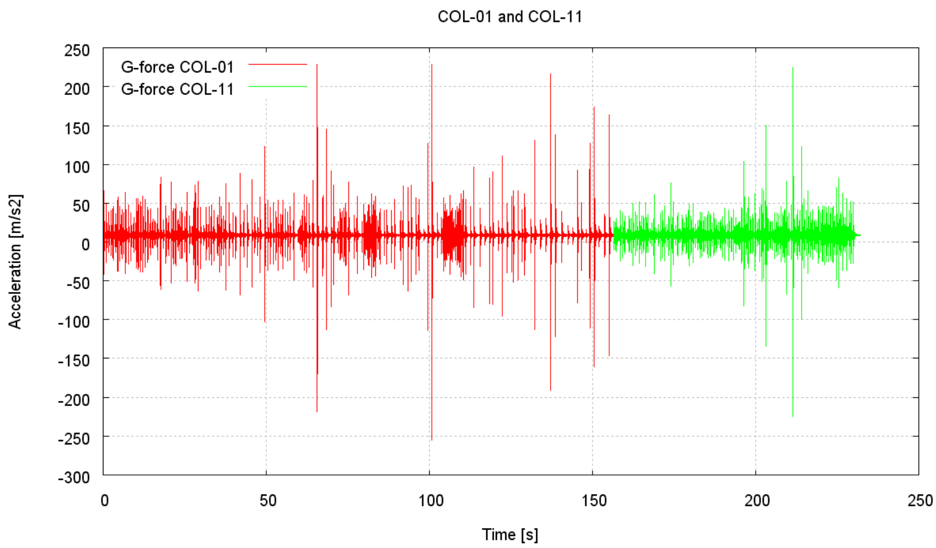


Figure 14. Acceleration of the pool bottom in COL-01 and COL-11 plotted in the same figure.

Figure 15 shows a 0.3 seconds interval photograph series (captured from the high speed recording of the Casio Exilim EX-F1 digital camera) from COL-11 of the development and collapse of a single steam bubble at the blowdown pipe outlet. The bubble in question is the one that caused the largest measured loads during the whole recorded interval in this experiment. Detailed measurements of the corresponding bubble behavior from a one second time interval are shown in the following figures. In Figure 16, the temperature inside and at the outlet the blowdown pipe is shown. It can be seen that water ingress back into the pipe after the collapse of the steam bubble reaches only the lowest measurement point (T1) in the pipe. The corresponding pressure loads are registered also by the middle elevation pressure sensor (P2), Figure 17. The highest pressure load is, however, measured by P5 below the blowdown pipe, Figure 18. Figure 19 and Figure 20 show the vertical movement and acceleration of the test vessel, respectively.

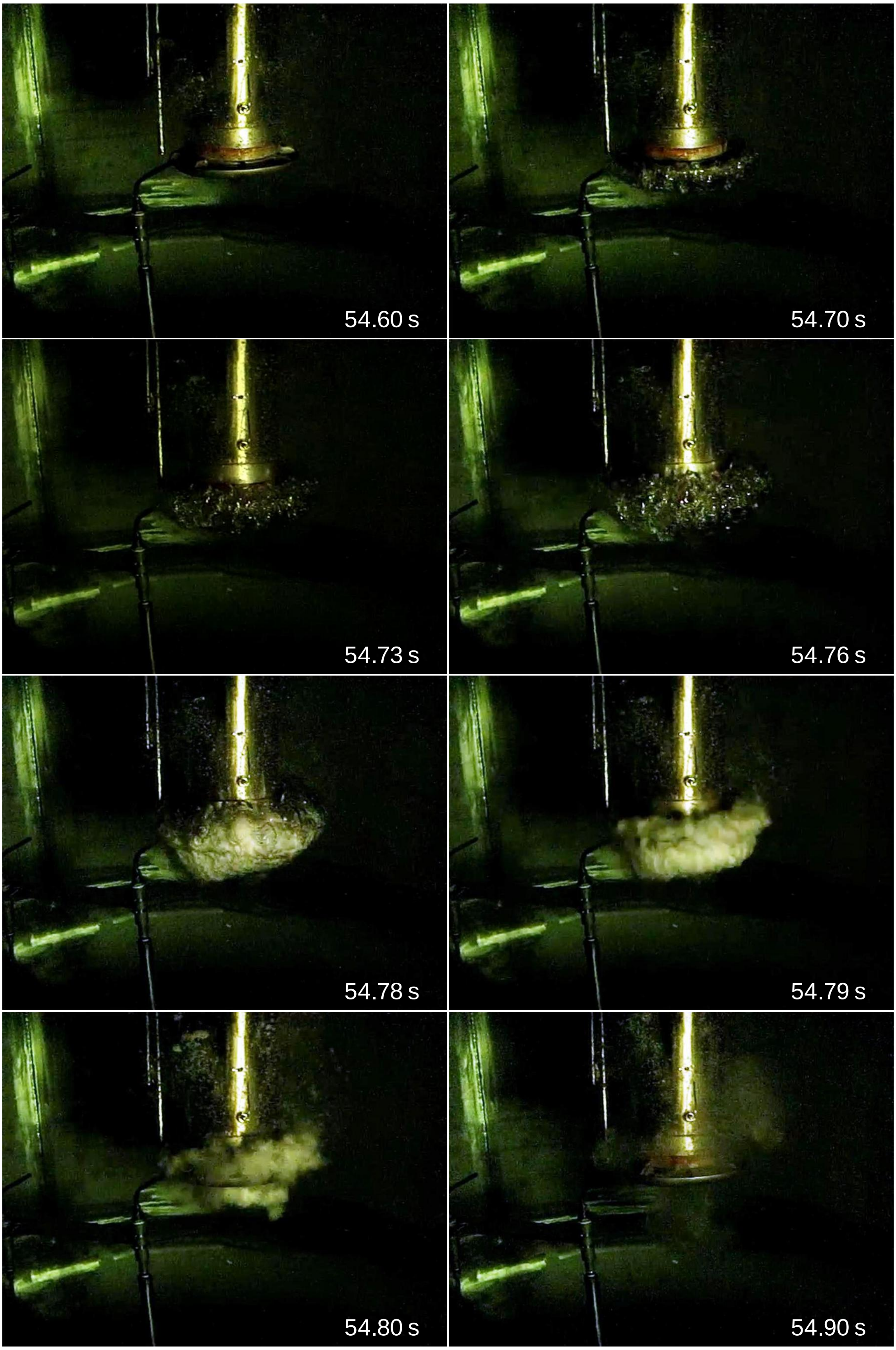


Figure 15. Development and collapse of a steam bubble at the blowdown pipe outlet in COL-11.

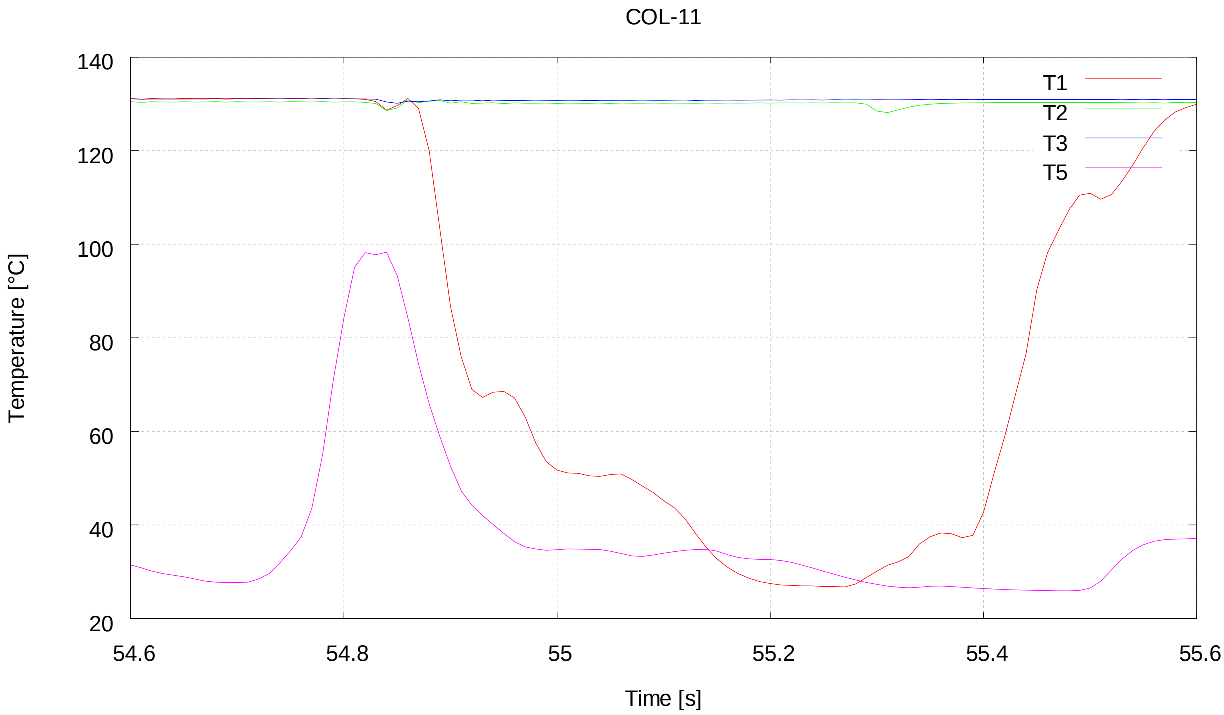


Figure 16. Temperature behavior inside and at the blowdown pipe outlet during the formation and collapse of a steam bubble in COL-11.

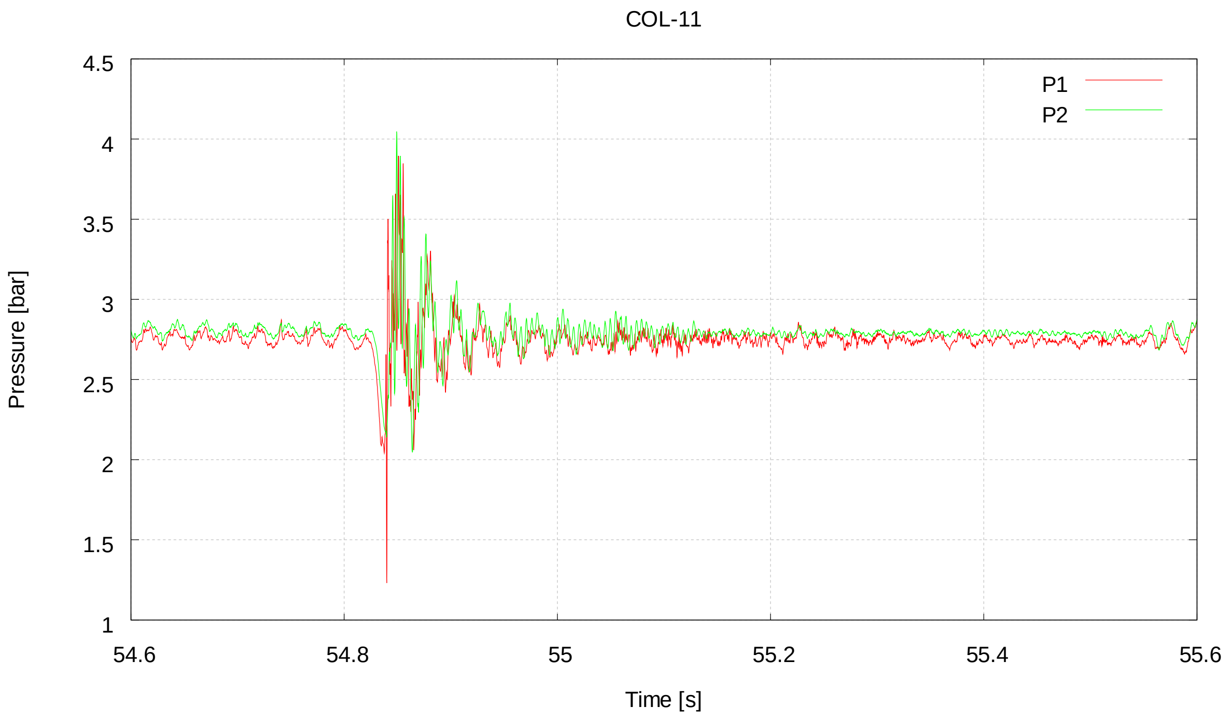


Figure 17. Pressure loads inside the blowdown pipe during the formation and collapse of a steam bubble in COL-11.

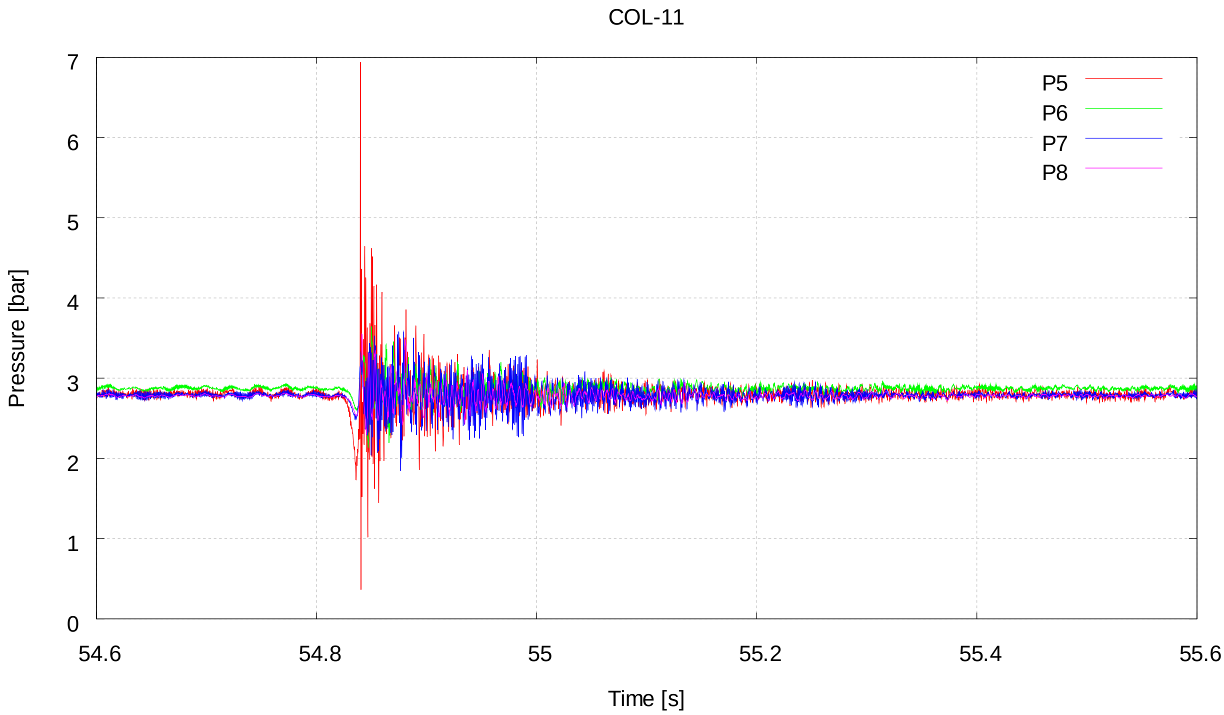


Figure 18. Pressure loads in the pool side during the formation and collapse of a steam bubble in COL-11.

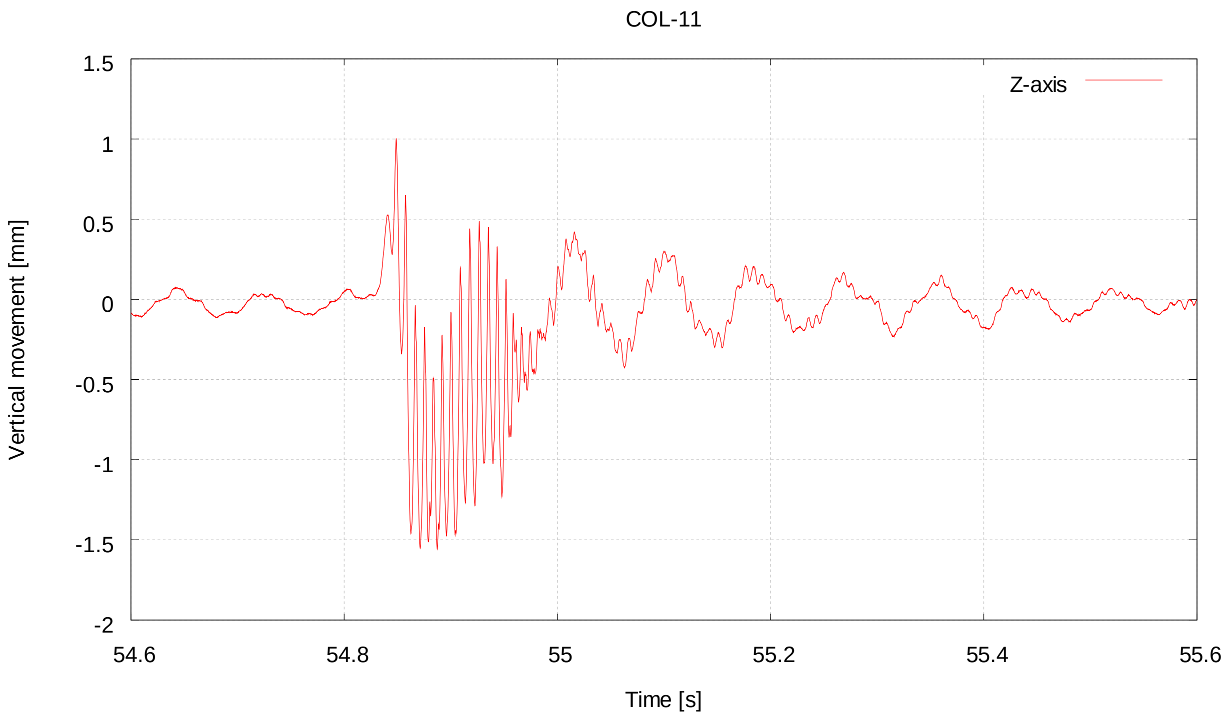


Figure 19. Vertical movement of the test vessel during the formation and collapse of a steam bubble in COL-11.

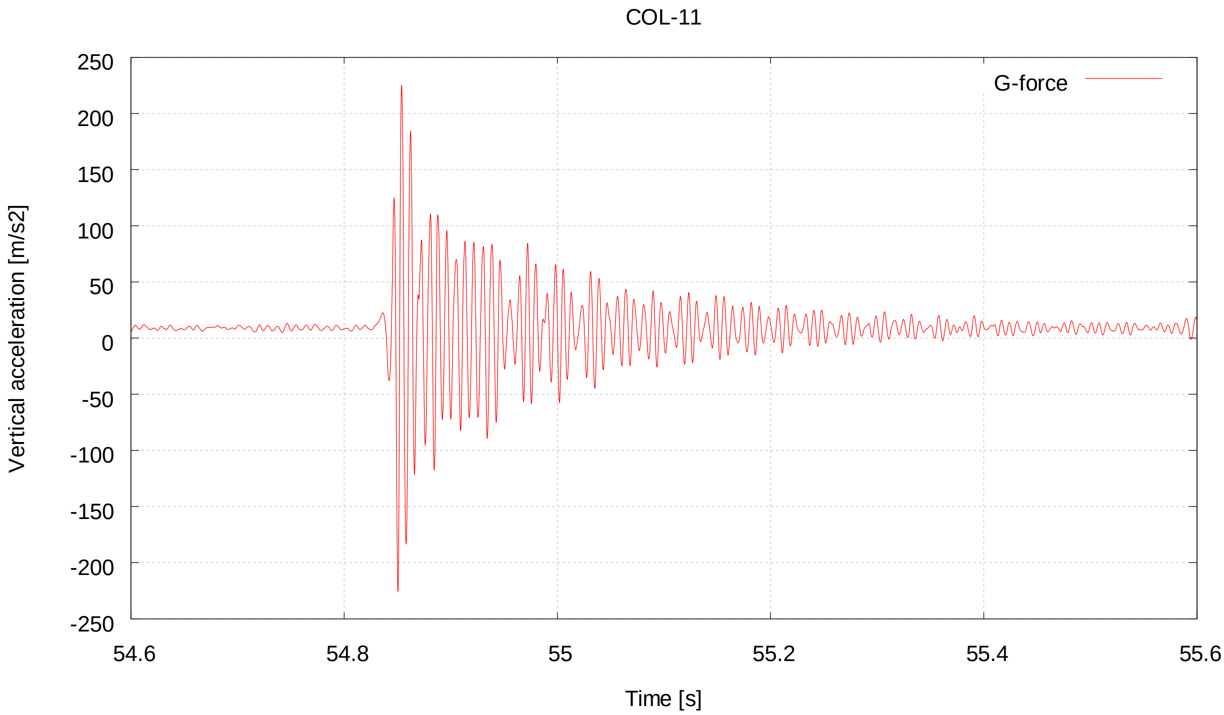


Figure 20. Vertical acceleration of the test vessel during the formation and collapse of a steam bubble in COL-11.

The general behavior of steam bubbles at the blowdown pipe outlet changed slightly after the installation of the collar. On the basis of visual observations it can be concluded that the condensation process is more “controlled” and not so violent. Captures from the high speed video show that the shape of the bubbles is more compact and donut like with the collar installed (Figure 21). The same observation can be made from all pairs of collar and collarless experiments with similar test conditions.

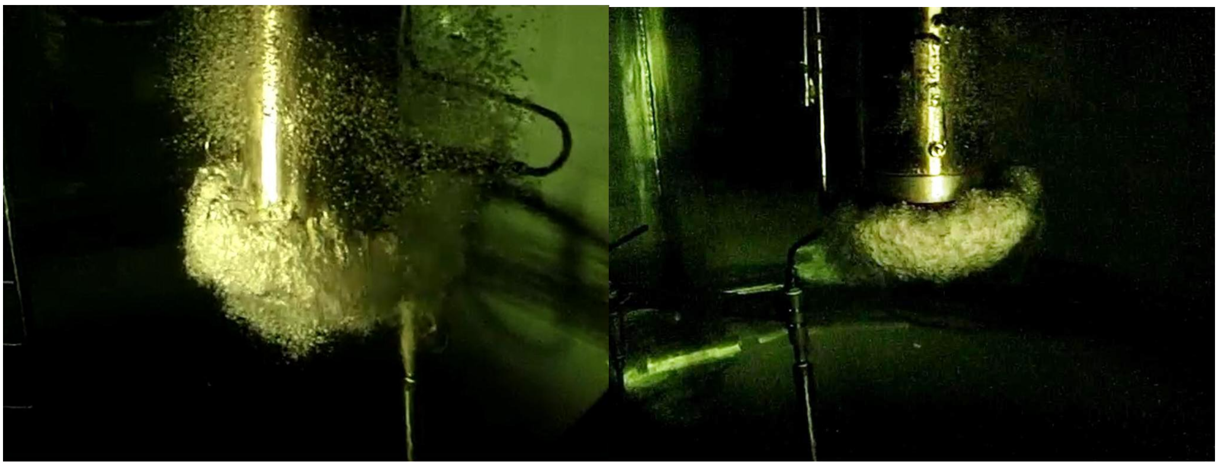


Figure 21. Steam bubble at the blowdown pipe outlet without (left) and with (right) the collar.

4.2 EXPERIMENTS WITH INITIAL 25 °C POOL WATER

In experiments COL-02 and COL-12, the initial temperature of pool water was 25 °C. COL-02 was executed with the straight blowdown pipe and COL-12 with the collar. The steam flow rate was in the range of 600…550 g/s during COL-02 and 580…510 g/s during COL-12, Figure 22. Dry well and wet well pressures were about 0.4 bar higher during COL-02 than during COL-12. These small differences in the test parameters between the experiments are not believed to have any significant effect on the behavior of the interested phenomena. Comparison of the results is therefore considered to be valid.

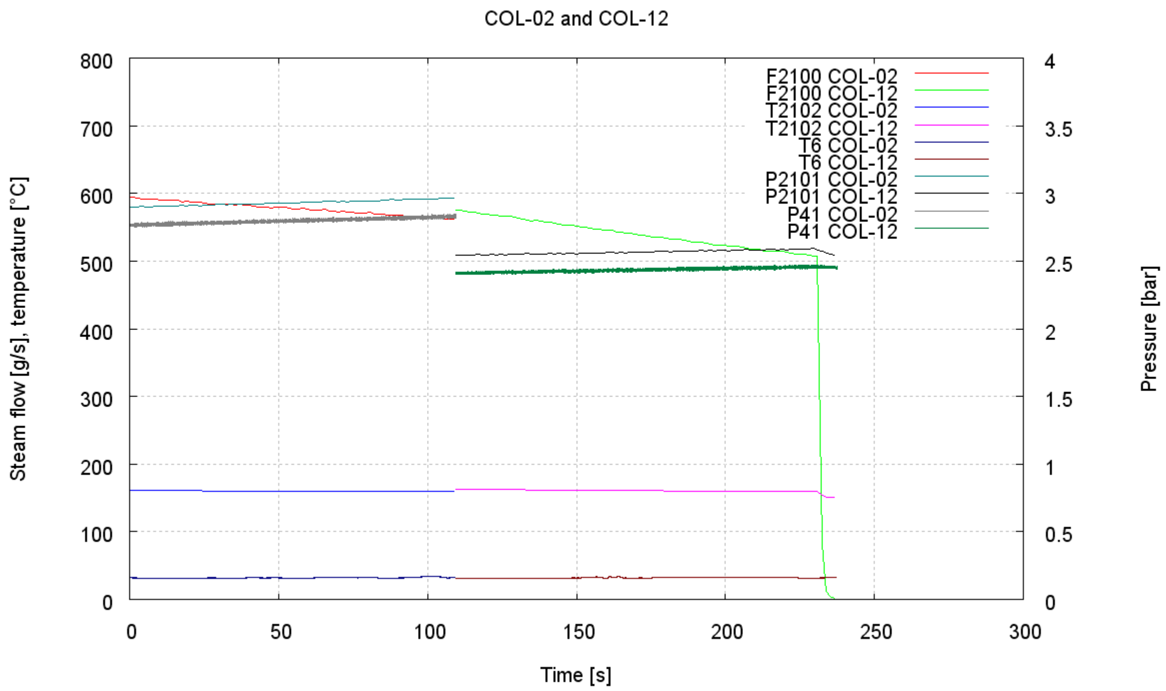


Figure 22. Flow rate (F2100), temperature of incoming steam (T2102) and pool water (T6) and pressure in the dry well (P2101) and wet well (P41) in COL-02 and COL-12 plotted in the same figure. (Note that the actual timescale is discontinuous between the experiments in all figures.)

Measurement data of COL-02 and COL-12 is very similar to COL-01 and COL-11. For example, the pressure transducer P1 inside the blowdown pipe registered higher pressure pulses without the collar than with it, Figure 23. Also, the registered loads in the pool were in the same range with the straight pipe as with the collar, see Figure 24.

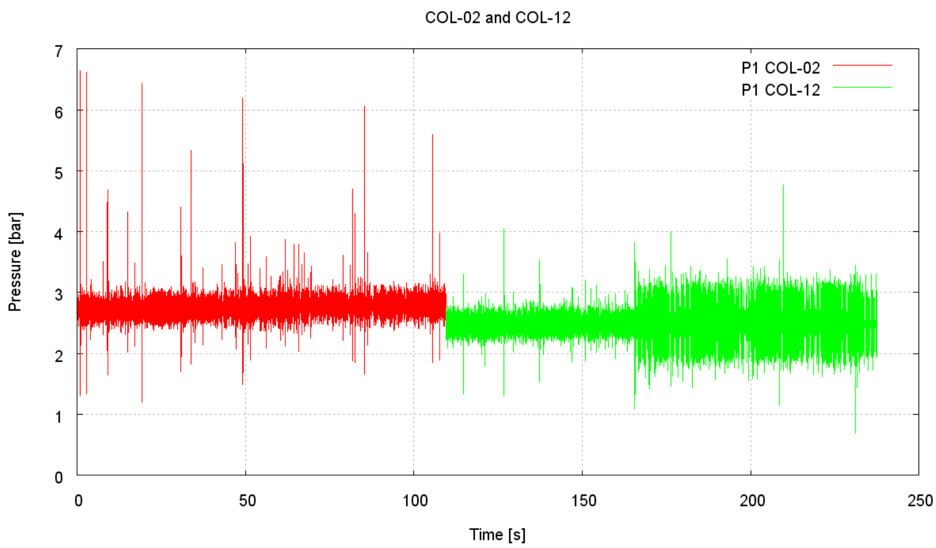


Figure 23. Pressure P1 in COL-02 and COL-12 plotted in the same figure.

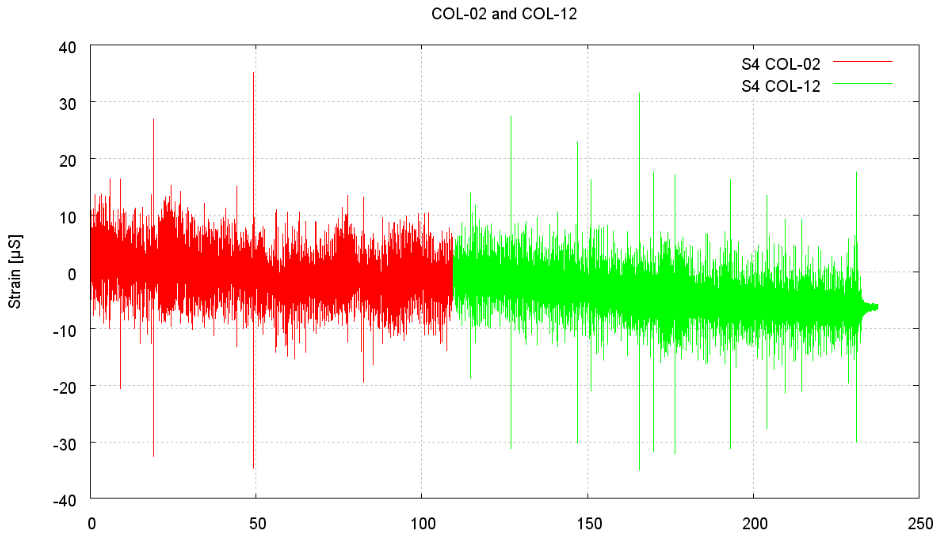


Figure 24. Strain S4 in COL-02 and COL-12 plotted in the same figure.

4.3 EXPERIMENTS WITH INITIAL 50 °C POOL WATER

In experiments COL-03 and COL-13, the initial temperature of pool water was 50 °C and the steam flow rate approximately 400 g/s. Also the pressure in the dry well and wet well was the same during the experiments, Figure 25. COL-03 was executed with the straight blowdown pipe and COL-13 with the collar.

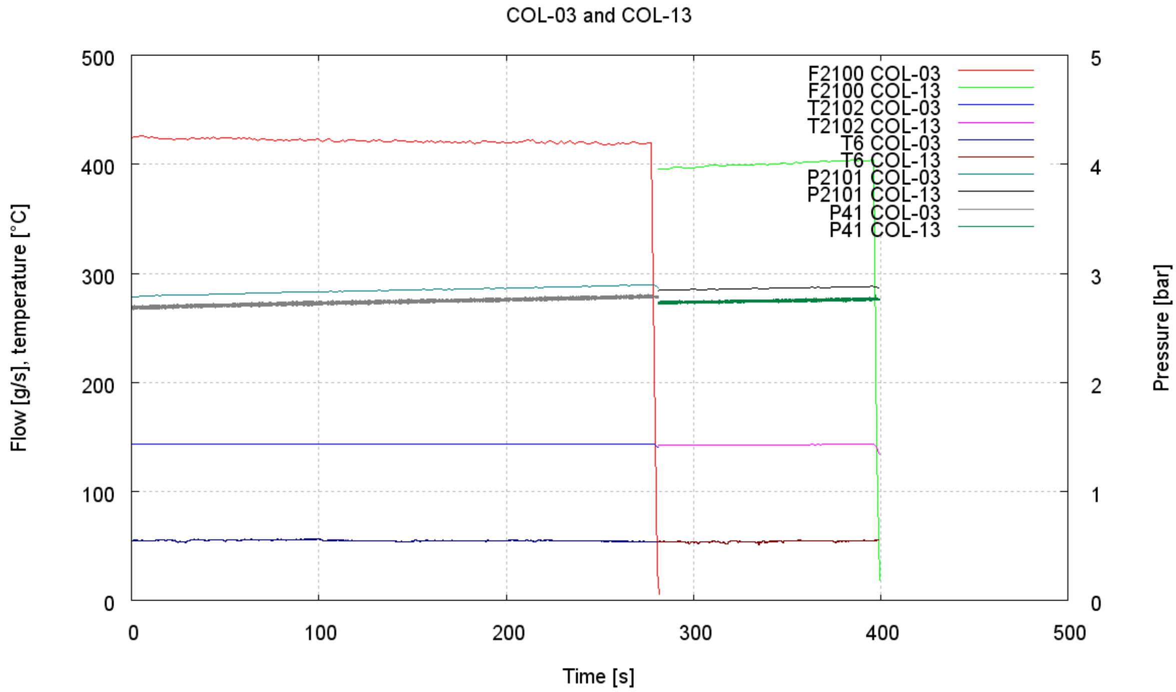


Figure 25. Flow rate (F2100), temperature of incoming steam (T2102) and pool water (T6) and pressure in the dry well (P2101) and wet well (P41) in COL-03 and COL-13 plotted in the same figure. (Note that the actual timescale is discontinuous between the experiments in all figures.)

Due to warm pool water no high pressure pulses were measured inside the blowdown pipe. Furthermore, the steam/water interface didn't move (strongly) up and down inside the blowdown pipe in either experiment, Figure 26.

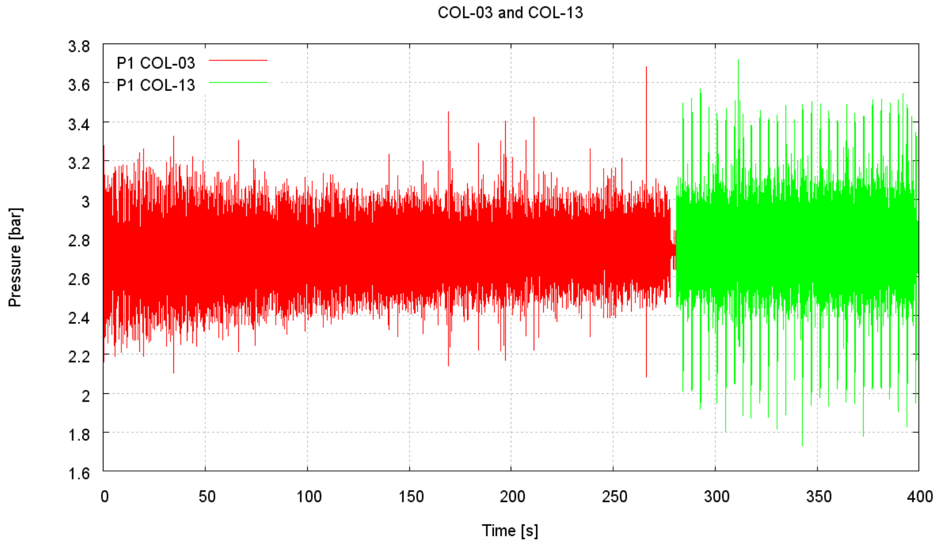


Figure 26. Pressure P1 in COL-03 and COL-13 plotted in the same figure.

In COL-13, two to five times higher loads were registered in the condensation pool than in COL-03, Figure 27…Figure 29. For instance, the maximum pressure pulse registered by pressure transducer P5 during COL-13 was 350 kPa (Figure 27) while during COL-03 it was no more than 70 kPa.

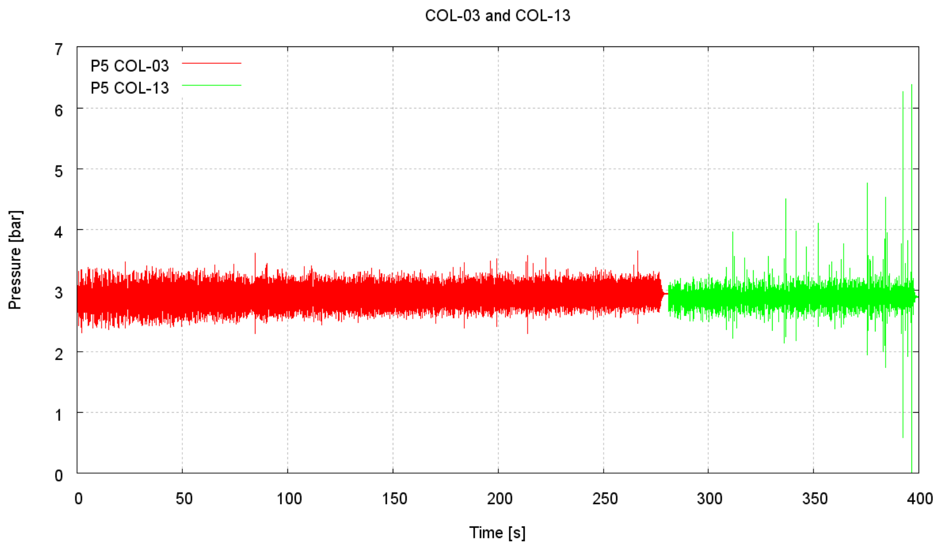


Figure 27. Pressure P5 in COL-03 and COL-13 plotted in the same figure.

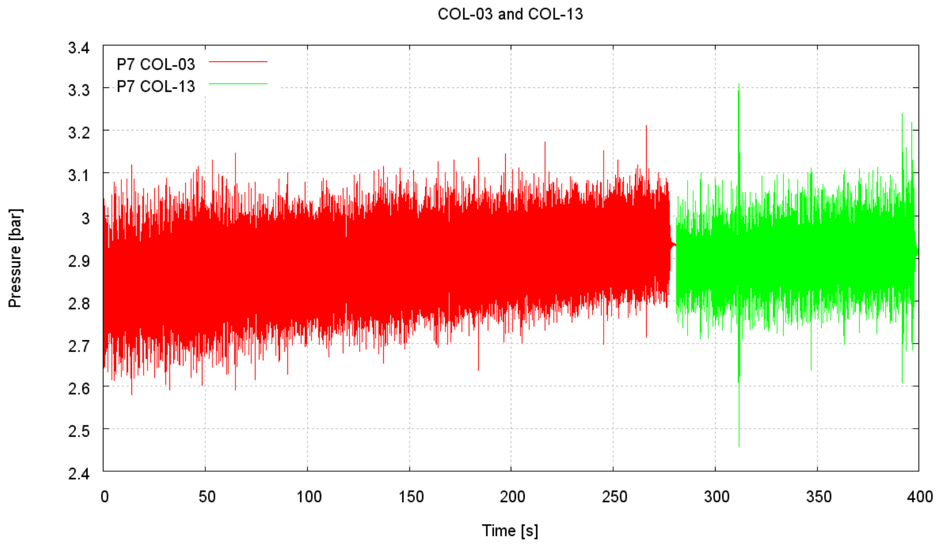


Figure 28. Pressure P7 in COL-03 and COL-13 plotted in the same figure.

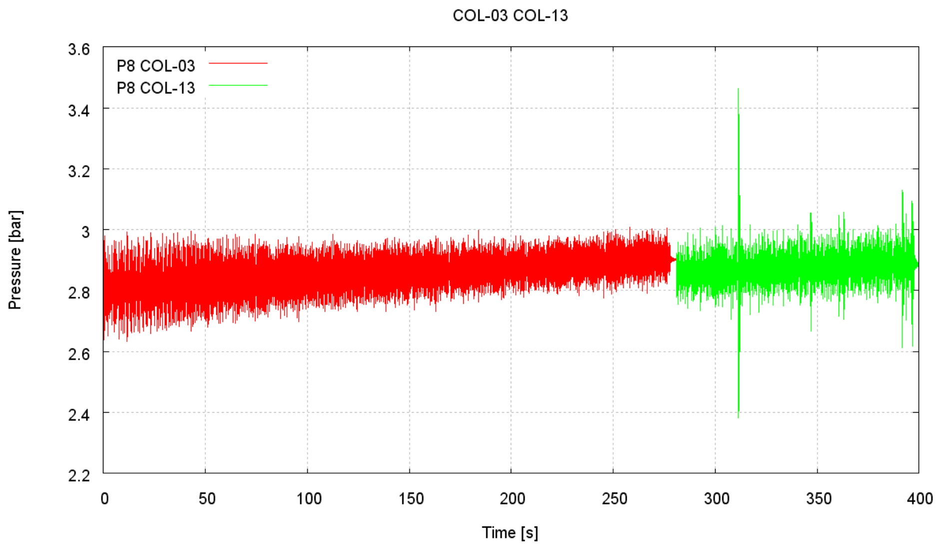


Figure 29. Pressure P8 in COL-03 and COL-13 plotted in the same figure.

4.4 EXPERIMENTS WITH INITIAL 55 °C POOL WATER

In experiments COL-04 and COL-14, the initial temperature of pool water was 55 °C. The steam flow rate ranged from 630 to 540 g/s, Figure 30. The pressure inside the dry well and wet well was about 0.6 bar higher in COL-04 than in COL-14. COL-04 was a reference test with the straight blowdown pipe and COL-14 was executed with the collar. This difference in the test parameters between the experiments is not believed to have any significant effect on the behavior of the interested phenomena. Comparison of the results is therefore considered to be valid.

In COL-14, two to even 12 times higher loads were registered in the pool side than in COL-04. For instance the maximum pressure pulse registered by pressure transducer P5 during COL-14 was 470 kPa (Figure 31) while in COL-04 it was no more than 40 kPa.

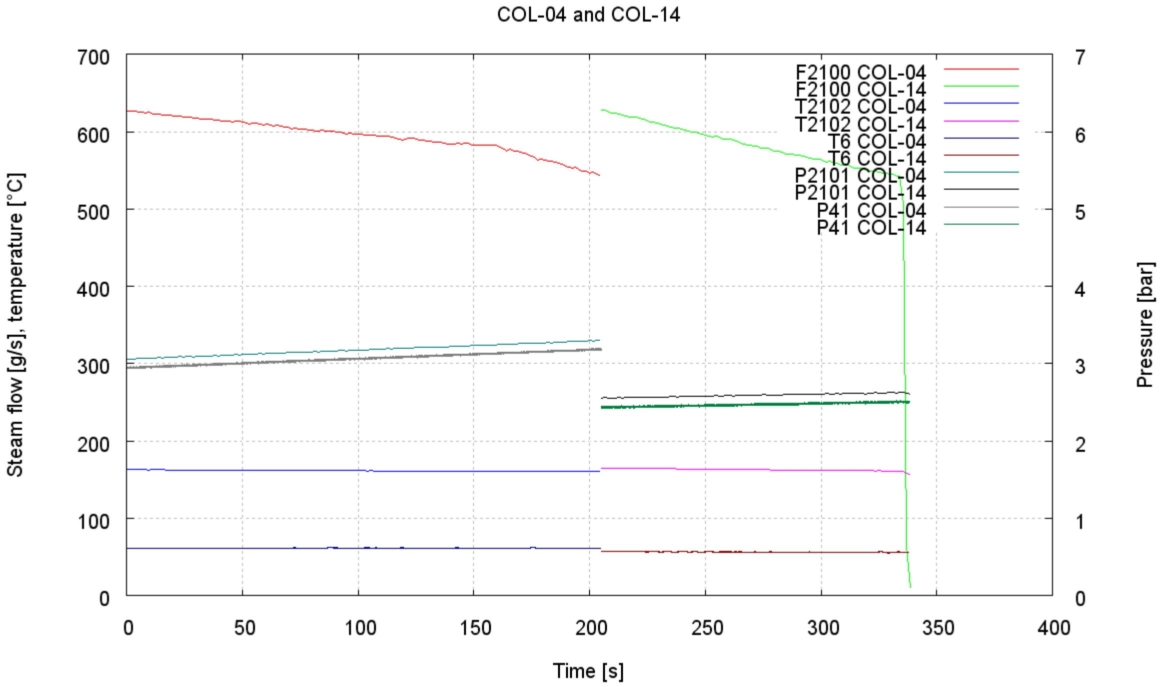


Figure 30. Flow rate (F2100) and temperatures of incoming steam (T2102) and pool water (T6) in COL-04 and COL-14 plotted in same figure. (Note that actual timescale is discontinuous between the experiments in all figures.)

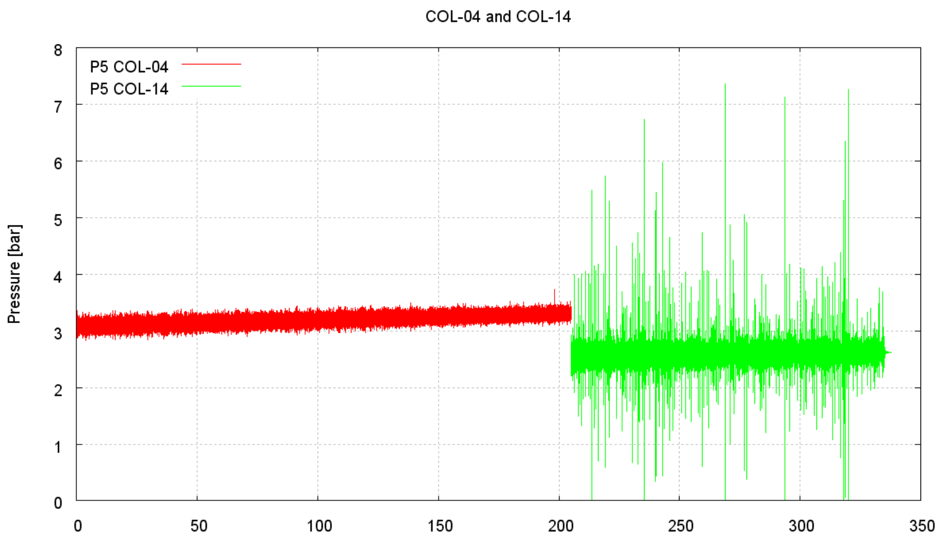


Figure 31. Pressure P5 in COL-04 and COL-14 plotted in the same figure.

5 SUMMARY AND CONCLUSIONS

This report summarizes the results of the experiments with the modified blowdown pipe outlet carried out in April and May 2009 with the PPOOLEX test facility designed and constructed at Lappeenranta University of Technology. The main purpose of the experiment series was to study the effect of a collar design on loads caused by chugging phenomena (rapid condensation) while steam is discharged through a vertical pipe into the condensation pool.

The PPOOLEX test facility is a closed stainless steel vessel divided into two compartments, dry well and wet well. A scaled down collar manufactured according to the design used at the Forsmark plant in Sweden and attached to the outlet of the blowdown pipe was used in ten experiments. Four reference experiments with a collarless straight pipe were also carried out.

In the experiments, steam was blown into the dry well compartment and from there through a DN200 (∅219.1x2.5) blowdown pipe down to the condensation pool filled with water. Before each experiment the condensation pool was filled with 20–25 or 50–55 °C water to the level of 2.14 m i.e. the blowdown pipe outlet was submerged by 1.05 m. The steam flow rate varied from 400 to 1200 g/s and the temperature of incoming steam from 142 to 185 °C.

In the experiments with 20–25 °C pool water even 10 times higher pressure pulses were measured inside the blowdown pipe in the case of the straight pipe than with the collar. In this respect, the collar design worked as planned and removed the high pressure spikes from the blowdown pipe. Meanwhile, there seemed to be no suppressing effect on the loads due to the collar in the pool side in this temperature range. Registered loads in the pool (pressure pulses inside the pool, strains on the outer wall of the pool bottom, vertical acceleration and movement of the pool bottom) were approximately in the same range (or even a little higher) with the collar as with the straight pipe.

In the experiments with 50–55 °C pool water no high pressure pulses were measured inside the blowdown pipe either with the straight pipe or with the collar. In this case, more of the suppressing effect is probably due to the warmer pool water than due to the modified pipe outlet. It has been observed already in the earlier experiments with a straight pipe in the POOLEX and PPOOLEX facilities that warm pool water has a diminishing effect on water hammers and pressure loads inside the blowdown pipe.

However, warm water seems not to prevent pressure loads in the condensation pool. Even an order of magnitude higher loads were measured with the collar than without it at the blowdown pipe outlet (measurement P5). At least in the 50–55 °C temperature range, the collar doesn’t seem to work as planned. Instead, it looks like it can even magnify pressure loads in the condensation pool.

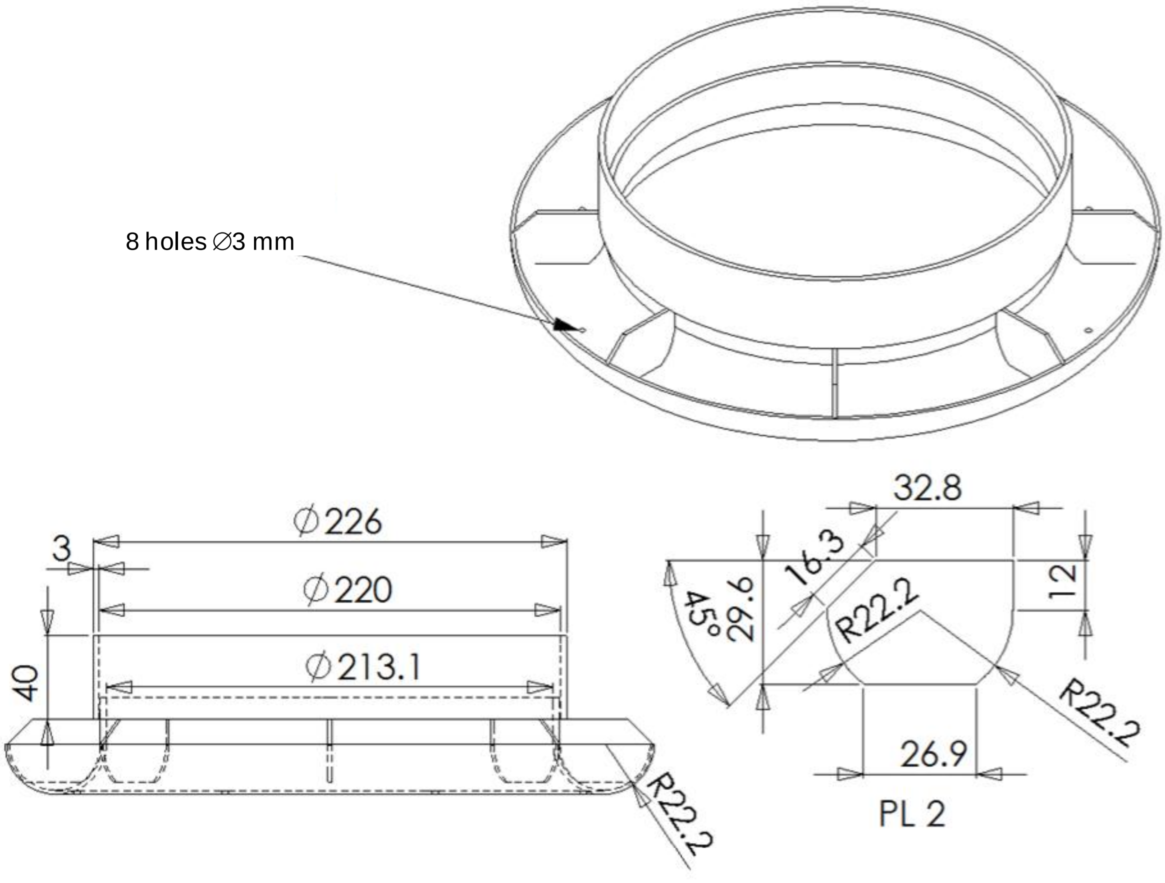
6 REFERENCES

1. Puustinen, M., Laine, J., Characterizing Experiments with the PPOOLEX Facility. Lappeenranta University of Technology. 2008. Research Report POOLEX 1/2007.
2. Laine, J., Puustinen, M., Steam Line Rupture Experiments with the PPOOLEX Facility. Lappeenranta University of Technology. 2008. Research Report POOLEX 2/2007.
3. Puustinen, M., Laine, J., Räsänen, A., PPOOLEX Experiments on Thermal Stratification and Mixing. Lappeenranta University of Technology. 2009. Research Report POOLEX 1/2008.
4. Laine, J., Puustinen, M., PPOOLEX Experiments on Wall Condensation. Lappeenranta University of Technology. 2009. Research Report POOLEX 3/2008.
5. Puustinen, M., Partanen, H., Räsänen, A., Purhonen, H., PPOOLEX Facility Description. Lappeenranta University of Technology. 2007. Technical Report POOLEX 3/2006.
6. Tuunanen, J., Kouhia, J., Purhonen, H., Riikonen, V., Puustinen, M., Semken, R. S., Partanen, H., Saure, I., Pylkkö, H., General Description of the PACTEL Test Facility. Espoo: VTT. 1998. VTT Research Notes 1929. ISBN 951-38-5338-1.

7. http://www.focusnordic.fi
8. Räsänen, A., Mittausjärjestelmä lauhtumisilmiöiden tutkimukseen. Lappeenranta University of Technology. 2004. Master's Thesis. In Finnish.

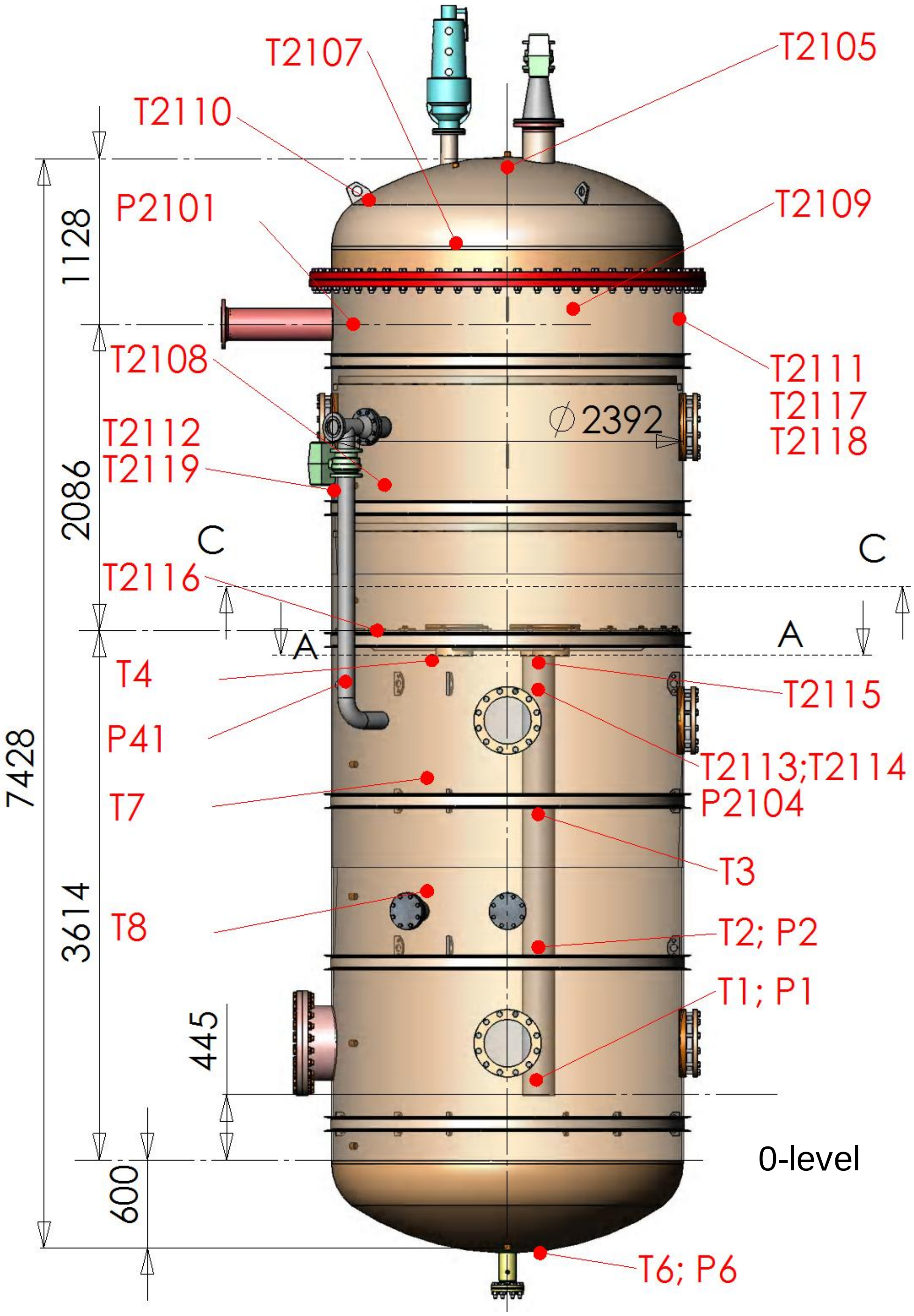
APPENDIX 1: DRAWINGS OF THE COLLAR

3D-sketch of the collar.

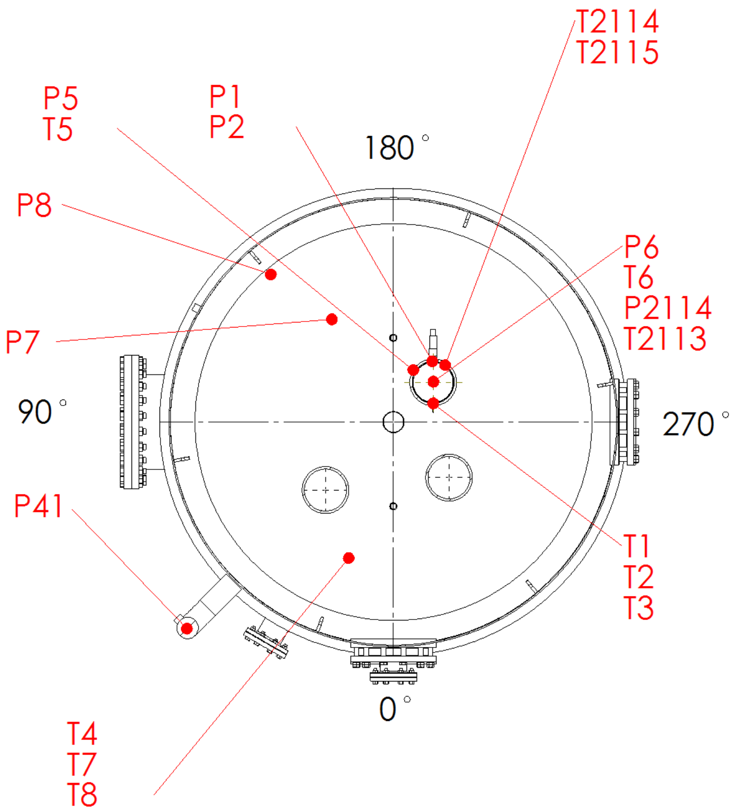


Dimensioning of the collar.

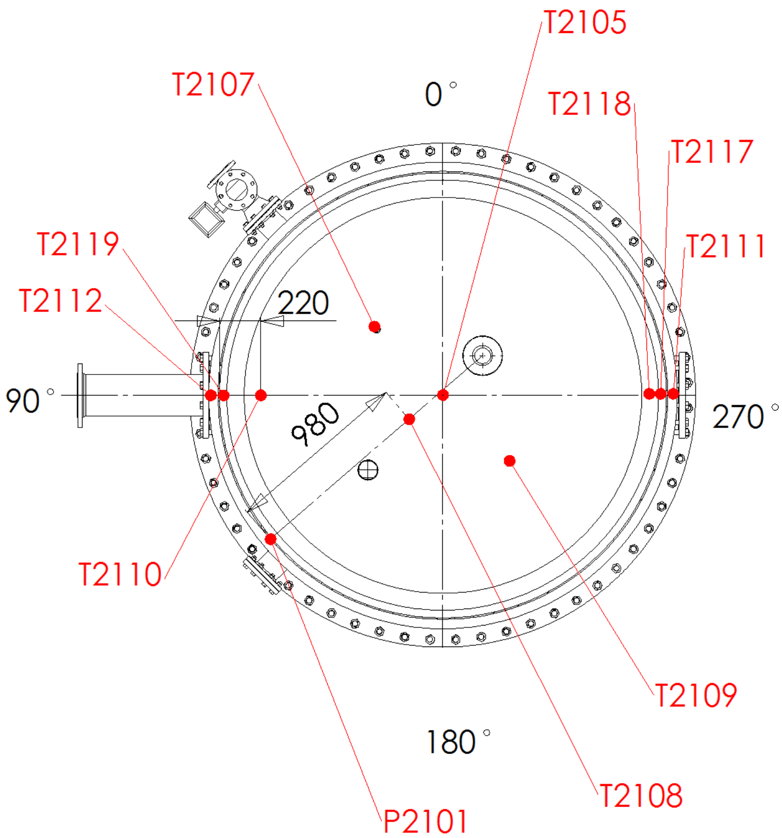
APPENDIX 2: INSTRUMENTATION OF THE PPOOLEX TEST FACILITY



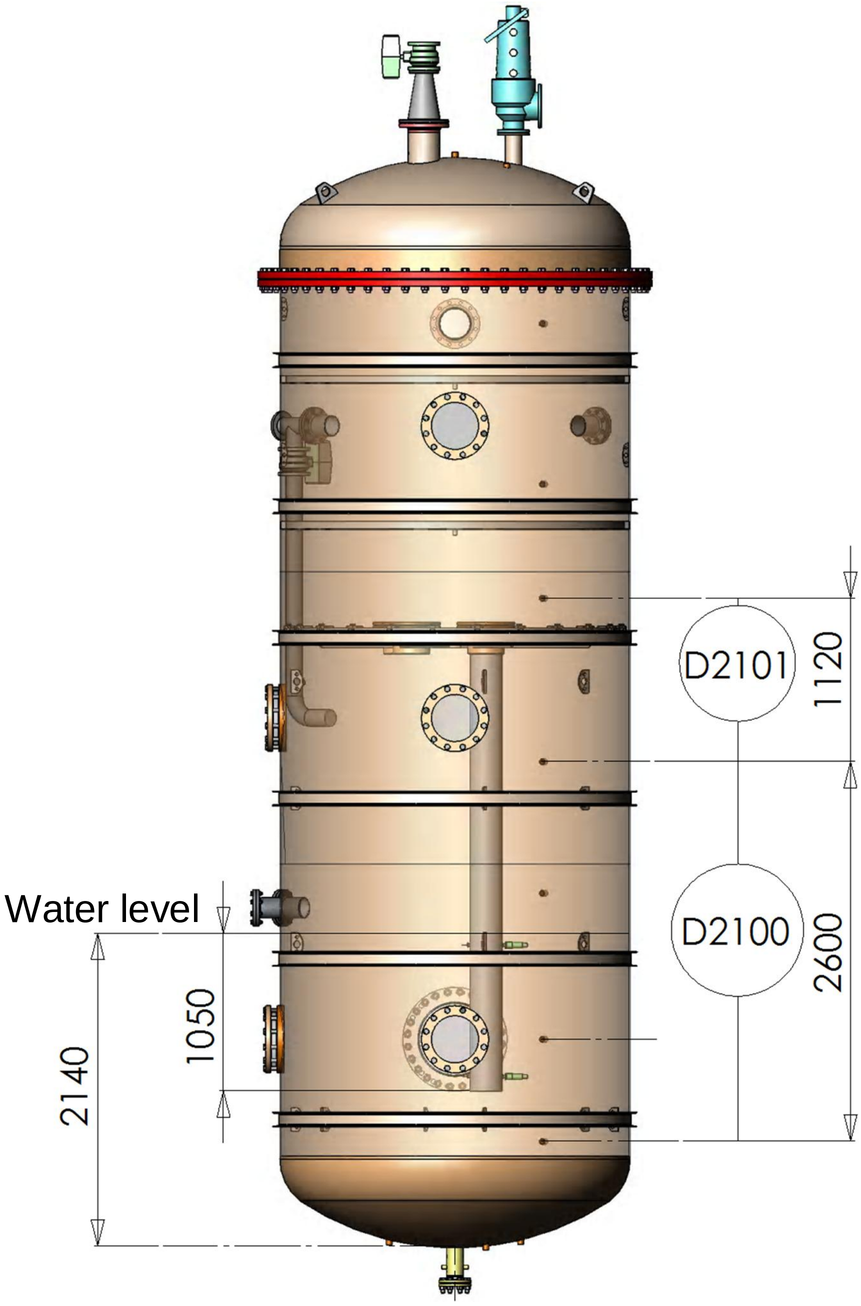
Test vessel measurements.



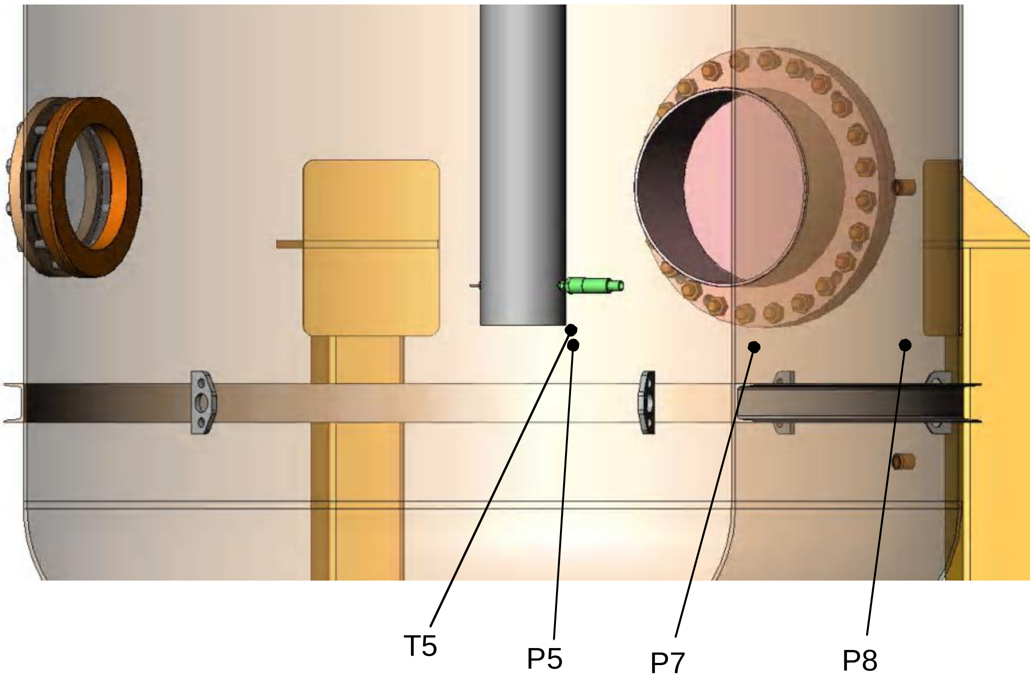
Cross-section A-A.



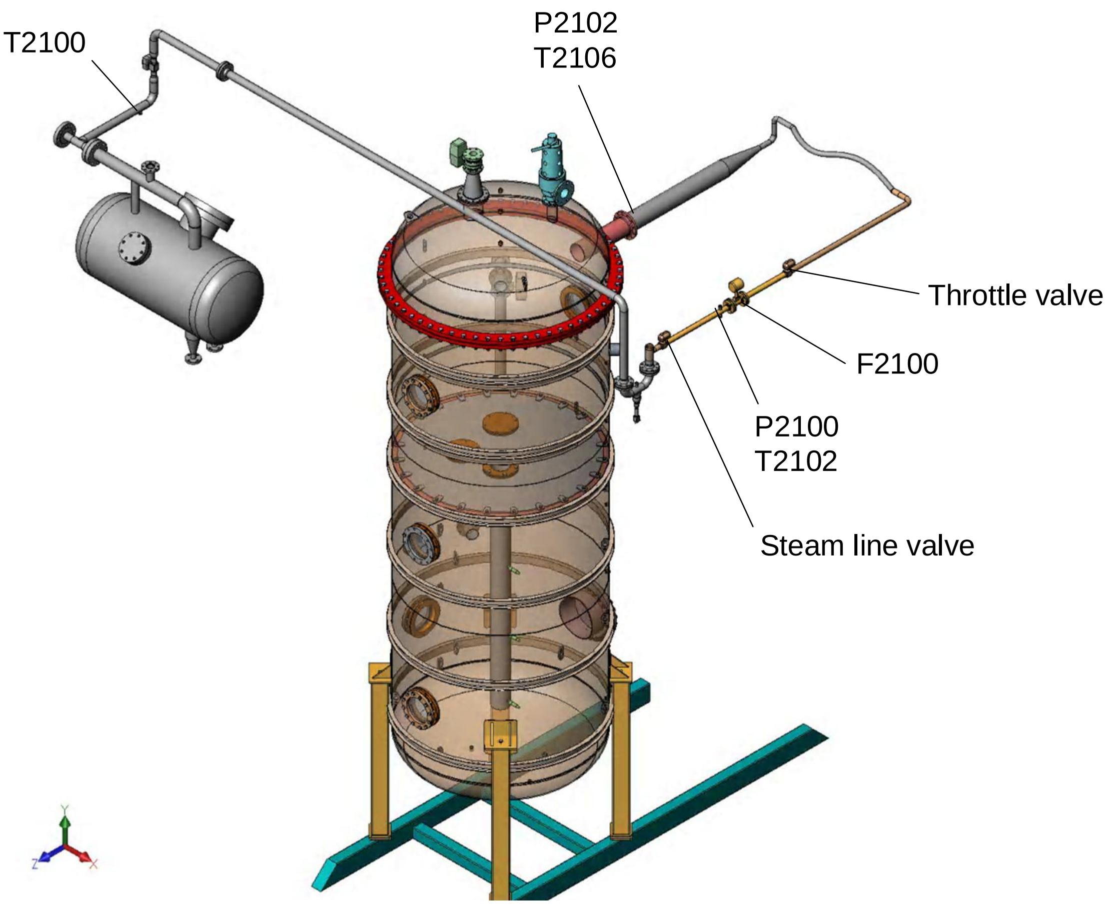
Cross-section C-C.



Test vessel measurements.



Pressure and temperature measurements at the blowdown pipe outlet.



Measurements in the steam line.

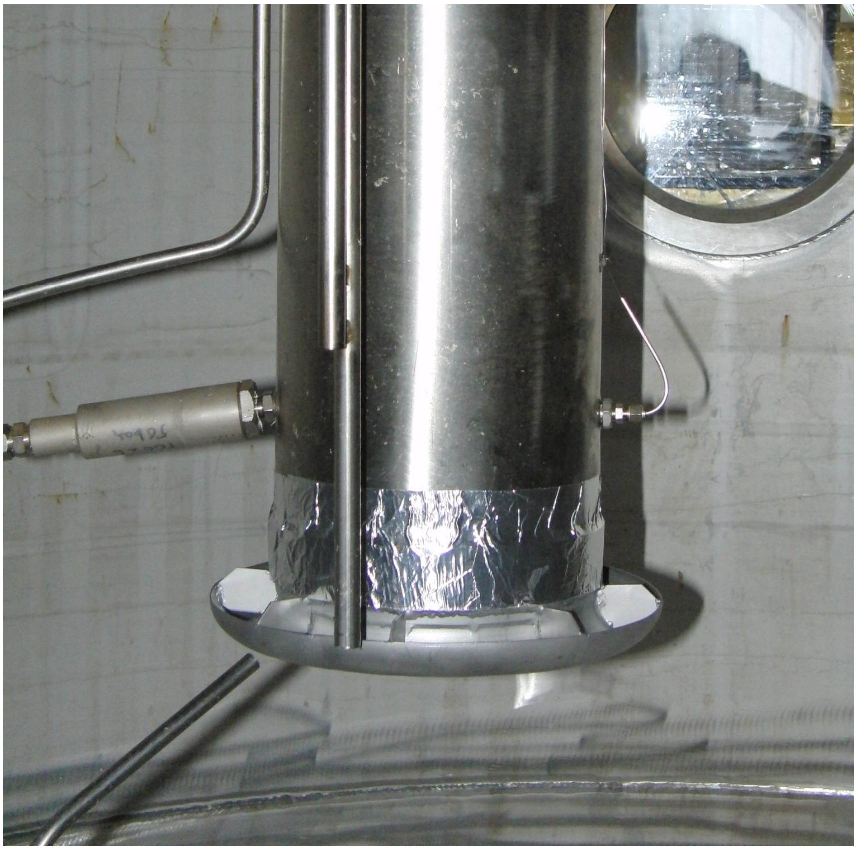
Measurement	Code	Elevation	Angle	Location	Error estimation
Pressure	P1	545	214	Blowdown pipe	±0.7 bar
Temperature	T1	545	245	Blowdown pipe	±1.8 °C
Pressure	P2	1445	214	Blowdown pipe	±0.7 bar
Temperature	T2	1445	245	Blowdown pipe	±1.8 °C
Temperature	T3	2345	245	Blowdown pipe	±1.8 °C
Temperature	T4	3410	20	Wet well gas space	±1.8 °C
Pressure	P5	395	198	Blowdown pipe outlet	±0.7 bar
Temperature	T5	420	198	Blowdown pipe outlet	±1.8 °C
Pressure	P6	-1060	225	Wet well bottom	±0.5 bar
Temperature	T6	-1060	225	Wet well bottom	±1.8 °C
Pressure	P7	395	135	Wet well	±0.4 bar
Temperature	T7	2585	20	Wet well	±1.8 °C
Pressure	P8	395	135	Wet well	±0.4 bar
Temperature	T8	1760	20	Wet well	±1.8 °C
Pressure	P41	3600	45	Wet well gas space	±0.1 bar
Flow rate	F2100	-	-	Steam line	±4.9 l/s
Pressure	P2100	-	-	Steam line	±0.5 bar
Temperature	T2100	-	-	Steam line beginning	±3.5 °C
Pressure	P2101	5700	90	Dry well	±0.06 bar
Pressure	P2102	-	-	Inlet plenum	±0.06 bar
Temperature	T2102	-	-	Steam line	±3.5 °C
Pressure	P2104	3400	225	Blowdown pipe	±0.06 bar
Temperature	T2104	-245	180	Wet well outer wall	±2.9 °C
Temperature	T2105	6780	-	Dry well top	±3.1 °C
Temperature	T2106	-	-	Inlet plenum	±3.1 °C
Temperature	T2107	6085	45	Dry well middle	±1.9 °C
Temperature	T2108	4600	120	Dry well bottom	±3.1 °C
Temperature	T2109	5790	225	Dry well lower middle	±9.9 °C
Temperature	T2110	6550	90	Dry well outer wall	±1.8 °C
Temperature	T2111	5700	270	Dry well outer wall	±1.8 °C
Temperature	T2112	4600	90	Dry well outer wall	±1.8 °C
Temperature	T2113	3400	225	Blowdown pipe	±1.8 °C
Temperature	T2114	3400	220	Blowdown pipe	±1.8 °C
Temperature	T2115	3250	220	Blowdown pipe	±1.8 °C
Temperature	T2116	3600	135	Dry well floor	±1.8 °C
Temperature	T2117	5700	270	Dry well inner wall	±1.8 °C
Temperature	T2118	5700	270	Dry well, 10 mm from the wall	±1.8 °C
Temperature	T2119	4600	90	Dry well inner wall	±1.8 °C
Pressure diff.	D2100	100–2700	120	Wet well	±0.06 m
Pressure diff.	D2101	2700–3820	120	Across the floor	±0.09 bar
Strain	S1	-400	0	Bottom segment	Not defined
Strain	S2	-400	0	Bottom segment	Not defined
Strain	S3	-265	180	Bottom segment	Not defined
Strain	S4	-265	180	Bottom segment	Not defined
Vertical pool movement	Z-axis	892	180	Below pool bottom	Not defined
Pool bottom acceleration	G-force	892	180	Pool bottom	Not defined
Valve position	X1100	-	-	Steam line	Not defined
Steam partial pressure	X2102	4600	120	Dry well	Not defined

Measurements in the PPOOLEX facility for the COL experiments.

APPENDIX 3: TEST FACILITY PHOTOGRAPHS

Dry well compartment, relief valves and inlet plenum.

Inside view of the wet well compartment: blowdown pipe and intermediate floor.



Collar attached to the blowdown pipe outlet.

Pressure (P1, P5, P7 and P8) and temperature (T1 and T5) measurements at the blowdown pipe outlet.

Bibliographic Data Sheet **NKS-199**

Title	PPOOLEX Experiments with a Modified Blowdown Pipe Outlet
Author(s)	Jani Laine, Markku Puustinen, Antti Räsänen
Affiliation(s)	Lappeenranta University of Technology, Finland Nuclear Safety Research Unit
ISBN	978-87-7893-266-2
Date	August 2009
Project	NKS-R / POOL
No. of pages	29 + 8
No. of tables	5 + 1
No. of illustrations	31 + 12
No. of references	8

Abstract

This report summarizes the results of the experiments with a modified blowdown pipe outlet carried out with the PPOOLEX test facility designed and constructed at Lappeenranta University of Technology. Steam was blown into the dry well compartment and from there through a vertical DN200 blowdown pipe to the condensation pool. Four reference experiments with a straight pipe and ten with the Forsmark type collar were carried out. The main purpose of the experiment series was to study the effect of a blowdown pipe outlet collar design on loads caused by chugging phenomena (rapid condensation) while steam is discharged into the condensation pool.

The PPOOLEX test facility is a closed stainless steel vessel divided into two compartments, dry well and wet well. During the experiments the initial temperature level of the condensation pool water was either 20–25 or 50–55 C. The steam flow rate varied from 400 to 1200 g/s and the temperature of incoming steam from 142 to 185 C.

In the experiments with 20–25 C pool water, even 10 times higher pressure pulses were measured inside the blowdown pipe in the case of the straight pipe than with the collar. In this respect, the collar design worked as planned and removed the high pressure spikes from the blowdown pipe. Meanwhile, there seemed to be no suppressing effect on the loads due to the collar in the pool side in this temperature range. Registered loads in the pool were approximately in the same range (or even a little higher) with the collar as with the straight pipe.

In the experiments with 50–55 ºC pool water no high pressure pulses were measured inside the blowdown pipe either with the straight pipe or with the collar. In this case, more of the suppressing effect is probably due to the warmer pool water than due to the modified pipe outlet. It has been observed already in the earlier experiments with a straight pipe in the POOLEX and PPOOLEX facilities that warm pool water has a diminishing effect on water hammers and pressure loads inside the blowdown pipe.

However, warm water seems not to prevent pressure loads in the condensation pool. Even an order of magnitude higher loads were measured with the collar than without it at the blowdown pipe outlet (measurement P5). At least in the 50–55 ºC temperature range, the collar doesn’t seem to work as planned. Instead, it looks like it can even magnify pressure loads in the condensation pool.

Key words condensation pool, steam/air blowdown, blowdown pipe

---

Available on request from the NKS Secretariat, P.O.Box 49, DK-4000 Roskilde, Denmark.
Phone (+45) 4677 4045, fax (+45) 4677 4046, e-mail nks@nks.org, www.nks.org