BLOWDOWN OF ONSHORE AND OFFSHORE INSTALLATIONS

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SYNOPSIS

A computer program called BLOWDOWN has been developed to simulate the rapid blowdown of vessels and pipelines containing hydrocarbons. The program has been validated by comparison with many experiments, including measurements made during the blowdown of several complete onshore and offshore installations such as a gas treatment plant and some platforms. The way in which BLOWDOWN has been validated using the data from these full–scale tests and some lessons learned are presented here.

KEY WORDS

Blowdown, depressurisation, relief venting, hydrocarbons

1 INTRODUCTION

The rapid depressurisation or blowdown of a high pressure onshore installation, such as a natural gas transmission system, or an offshore installation, such as an oil or gas platform, is usually deliberate, for example to avoid the possiblity of rupture in the event of a fire or to minimise emissions at undesirable locations in the event of a leak. It can also be accidental, if part of a vessel (or its associated pipework or valving) or a pipeline is ruptured.

1.1 Hazards from blowdown

Blowdown can be a hazard for three main reasons. First, the very low temperatures generated within the fluid lead to a reduction in the temperature of the vessel walls and possibly to a temperature below the ductile–brittle transition temperature of the steel from which the walls are made. Second, it can lead to the formation of liquid condensate which can get carried over into a flare or vent system. Third, large total effluxes and high efflux rates can arise when the very large inventory in a big process vessel or pipeline is blown down.

1.2 Simulation of blowdown

Motivated by the need to predict hydrocarbon and vessel and line wall temperatures and also efflux rate, composition and phase, we have developed a computer program called BLOWDOWN for the simulation of blowdown [1–6]. Because the physical processes occurring during blowdown (fluid mechanics, heat and mass transfer and thermodynamics) are generally extremely complex, development of a complete model of blowdown is effectively impossible. The main objective of BLOWDOWN is, instead, to simulate all physically significant effects: all insignificant effects are eliminated. The judgement required in order to be able to select physically significant effects is based upon extensive experimental work which has been carried out concurrently with the modelling. The experiments have proved to be invaluable in this sense, as well as providing validation for predictions made using the model. A brief description follows of the main features of BLOWDOWN (details are given elsewhere [2,4]) and of its small–scale experimental validation (details are given elsewhere [3,4,7]). There then follows a description of its full–scale experimental validation using measurements made on an offshore platform and an onshore gas treatment plant (details of its validation using measurements from another platform are given elsewhere [6]). Some of the more important lessons learned are then discussed.

2 BLOWDOWN COMPUTER PROGRAM

The main features of BLOWDOWN are as follows.

2.1 Space and time discretisation

A vessel is assumed to comprise three distinct zones, with sharp interfaces: a top zone of gaseous hydrocarbon (including evaporated water and suspended liquid droplets which have condensed from the gas), a middle zone of liquid hydrocarbon (including dissolved water and gas bubbles which have evaporated from the liquid) and a bottom zone of free water (including dissolved hydrocarbons). A pipeline is divided axially into a number of discrete elements, the size of each of which is varied during the calculation in such a way that changes in physical properties along the element can be neglected. Blowdown is broken down into a sequence of discrete pressure steps, rather than time steps, because pressure is a more relevant parameter thermodynamically.

2.2 Fluid mechanics

Flow in topsides pipework is assumed to be quasi–steady (that is the mass flow rate is assumed to be spatially uniform in a given line) and, for a two–phase flow, to be homogeneous (that is the gas and liquid at a given cross–section are assumed to move at the same velocity). These assumptions are relaxed for pipelines. Standard correlations are used to determine friction factor and hold–up.

2.3 Thermodynamics

Experimental evidence has shown that it is most important to model the thermodynamics of blowdown accurately since failure to do so can lead to trajectories through phase (pressure–temperature–composition) space which are grossly in error. For this reason, thermodynamic, phase and transport properties of the multi–phase multi–component fluids are calculated rigorously by an extended principle of corresponding states.

2.4 Heat transfer

In a vessel, heat transfer is by forced/natural convection in the top zone, nucleate/film boiling in the middle zone, natural convection in the bottom zone, transient conduction through the wall (including any insulation and cladding) and forced/natural convection to the air or sea surrounding the vessel. In a pipeline or pipework, heat transfer is by forced convection to the fluid, transient conduction through the wall (including any insulation and cladding) and forced/natural convection to the air or sea surrounding the line. Standard correlations are used to determine heat transfer coefficients.

2.5 Orifice

Because transit times through an orifice are comparable with times for nucleation and growth of gas bubbles in a volatile liquid, non–equilibrium flashing flow can occur when just volatile liquid is fed to an orifice. Otherwise, the flow approaching an orifice is assumed to be in thermodynamic and phase equilibrium. When choking occurs in an orifice, whether for a gas, liquid or two–phase (gas–plus–liquid) flow, the mass flow rate is a maximum.

2.6 Balance equations

In order to close the system of equations describing blowdown, mass, energy and (for pipelines and pipework) momentum balances are performed. The reason why momentum balances are required for lines and not vessels is that vessels are assumed to be at a spatially uniform pressure; lines are not.

3 SMALL–SCALE EXPERIMENTAL VALIDATION

Small–scale blowdown experiments have been conducted on single vessels and lines.

3.1 Vessels

Experiments have been conducted using two vessels containing a range of fluids with blowdown from the top, bottom or side through chokes of various sizes: vessel A (flat ends) of length 1.524 m, inside diameter 0.273 m, wall thickness 25 mm and oriented either horizontally or vertically and vessel B (torispherical ends) of tan–to–tan length 2.250 m, inside diameter 1.130 m, wall thickness 59 mm and oriented vertically. The experiments using vessel A were conducted using representative fluids: nitrogen was used as a representative gas phase since it has critical properties in the same range as those of methane; carbon dioxide was used as a representative condensible phase such as propane. Fifteen experiments were conducted, covering a range of fluid compositions, blowdown directions and choke sizes. The initial pressure was about 150 bara and the initial temperature about 290 K in all cases. Blowdown times were of order 100 s. The experiments using vessel B (a sand scrubber from an offshore platform) were conducted on mixtures of methane, ethane and propane, together with some on nitrogen. Eighteen experiments were conducted, covering a range of fluid compositions, blowdown directions and choke sizes. The initial pressure was about 120 bara in all but two cases and the initial temperature between 290 K and 305 K in all cases. Blowdown times were of order 1500 s.

3.2 Pipelines

Experiments have been conducted on two horizontal lines [8] of length 100 m: line A was of bore 0.154 m and wall thickness 7 mm and line B was of bore 0.052 m and wall thickness 4 mm. The lines contained LPG (95 mole% propane and 5 mole% butane) at initial pressures of up to 23 bara and initial temperatures of about 290 K. Blowdown was through through orifices ranging in equivalent diameter from 20 mm to 150 mm. Eighty–four experiments were conducted, covering a range of initial pressures and orifice sizes.

3.3 Uncertainty

Comparison of predictions made using BLOWDOWN with measurements made during all of the small–scale experiments are generally in good agreement. The uncertainty in bulk fluid and wall temperatures, that is the discrepancy between predicted and measured values, is ±3 K. One point that must be borne in mind when making comparisons between measurements and BLOWDOWN predictions is that the program contains no disposable parameters. Thus there can be no adjustment of parameters in order to ensure good agreement between all of the measurements and (simultaneously) all of the predictions: BLOWDOWN is completely predictive.

4 FULL-SCALE EXPERIMENTAL VALIDATION

Small-scale validation is useful because conditions can be controlled so that extraneous effects are minimised and data with small uncertainty obtained. Full-scale validation is, however, also desirable, to ensure that all scale effects are properly accounted for.

4.1 Pipelines

Full-scale data on pipelines are scarce. Useful validatory information was provided by the accidental blowdown following the full-bore rupture of the gas line between Piper Alpha and MCP-01 which was 53804 m long and of bore 0.4191 m. The pressure in this line was monitored throughout the disaster at the intact (MCP-01) end [9]. Comparisons of the measured variation with time of the pressure at the intact end of the line with BLOWDOWN predictions are reported elsewhere [6].

4.2 Platform topsides

Experimental measurements have been made on three offshore platforms as follows:

- the partial blowdown of a gas platform (hereinafter platform A) comprising one gas train and involving flow through several connected vessels and lines;
- the blowdown of a gas platform (hereinafter platform B) comprising two gas trains and involving flow through several connected vessels and lines;
- the complete blowdown of a gas/condensate platform (hereinafter platform C) comprising three gas/condensate trains, an export system and a gas reinjection system and involving flow through a large number of connected vessels and lines.

Note that, in all of these cases, several vessels and interconnecting pipework are involved. In the case of platform C, several blowdown valves are also involved. Thus comparisons of BLOWDOWN predictions with measurements made during these experiments represent rather more severe tests than do the small-scale experiments involving a single vessel and a single blowdown valve.

4.3 Platform A

Platform A comprises two gas trains, each consisting of a fin-fan gas cooler, a gas scrubber and a glycol contactor with blowdown to high pressure vent for each train through a single blowdown valve. Only one train was blown down in the test. Comparisons of measurements (made using either meters already installed on the platform or specially-mounted thermocouples on the outside surfaces of vessels and lines) with BLOWDOWN predictions are reported elsewhere [6].

4.4 Platform B

Platform B comprises a test train and a production train, each of which comprises a separator (test and production, respectively), a glycol contactor tower and a gas/glycol exchanger and blowdown to high pressure vent through a single blowdown valve. Comparisons of measurements (made using either meters already installed on the platform or specially-mounted resistance thermometers on the outside surfaces of vessels and lines) with BLOWDOWN predictions have not yet been reported in the literature.

4.5 Platform C

Platform C comprises three trains, each of which in turn comprises:

- a Production Cooler (PC),
- a Production Separator (PS),
- a Glycol Contactor Inlet Scrubber (GCIS),
- a Glycol Contactor (GC) containing structured packing,
- a Condensate Cooler (CC),
- a Produced Water/Condensate Separator (PWCS),
- a Condensate Filter (CF),
- a Produced Condensate Coalescer (PCC).

It also comprises:

- a Reinjection Compressor Suction Scrubber (RCSS),

- a two–stage Reinjection Compressor (RC),
- a Reinjection Compressor Intercooler (RCI).

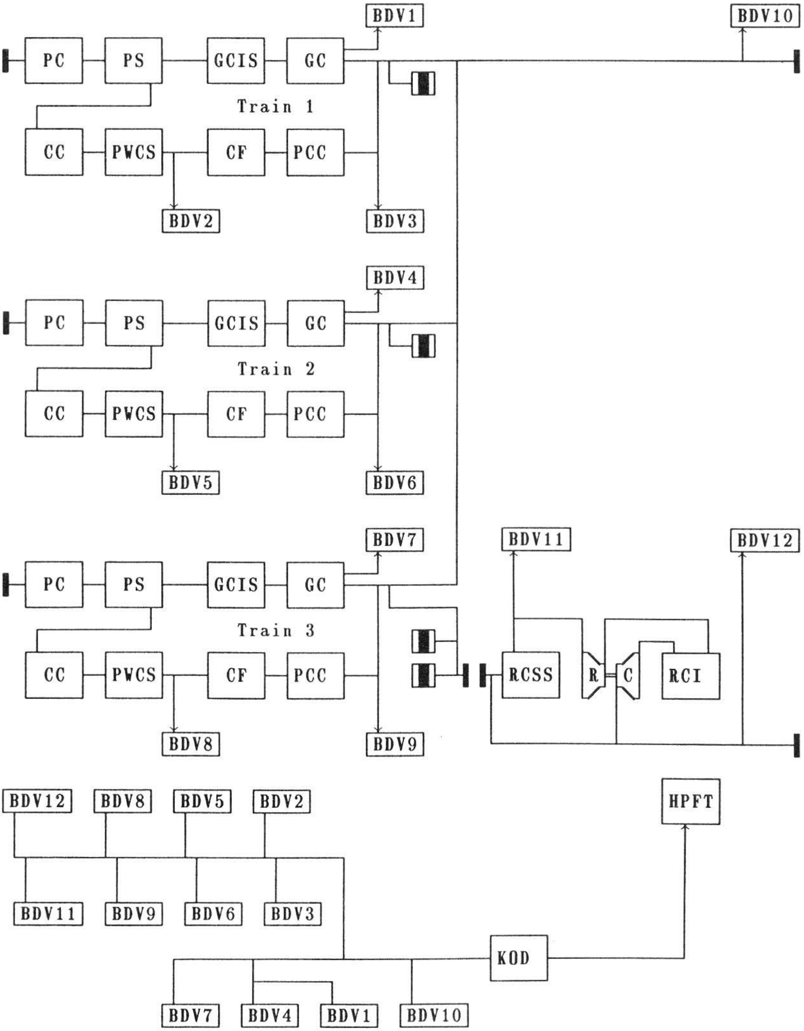
There is blowdown through through twelve blowdown valves (BDV1–BDV12) to:

- a Knock–Out Drum (KOD),

and then to:

- a High Pressure Flare Tip (HPFT).

Comparisons of measurements with predictions made using BLOWDOWN are summarised in Figures 1a–h. Solid lines refer to measurements (made using either meters already installed on the platform or specially–mounted resistance thermometer devices (RTDs) on the outside surfaces of vessels and lines) and broken lines to predictions.



4.5.1 *Predictions and measurements*

- Figure 1a is for meter P1 sited in the Train 2 production header downstream of the GC: there is very close agreement between the predicted and measured pressures.
- Figure 1b is for meter P2 sited in the export manifold upstream of BDV10: again, there is very close agreement between the predicted and measured pressures.
- Figure 1c shows that there is adequate agreement between predicted and measured outside wall temperatures on the Train 2 GC (RTD 5), the line between that GC and BDV4 (RTD 4) and the line immediately downstream of BDV4 (RTD 1).
- Figure 1d shows that there is reasonable agreement between predicted and measured outside wall temperatures on the flare header downstream of the junction between the two main flare headers (RTD 39 and RTD 40) immediately upstream of the junction with the line from BDV10.
- Figure 1e shows that there is good agreement between predicted and measured outside wall temperatures on the line from the export manifold upstream of BDV10 (RTD 20) and the line immediately downstream of BDV10 (RTD 21).
- Figure 1f shows that there is in contrast bad agreement between predicted and measured outside wall temperatures on the flare laterals downstream of BDV10 (RTD 44 and RTD 26). A possible reason for this is discussed below.
- Figure 1g shows that there is adequate agreement between predicted and measured outside wall temperatures on the flare header downstream of the junction with the flare lateral from BDV10 (RTD 27).
- Figure 1h shows that there is good agreement between predicted and measured outside wall temperatures on the flare header (RTD 42 and RTD 43) a little upstream of the KOD.

Comparison of predictions made using BLOWDOWN with measurements made during this test thus yields generally adequate agreement. With the exception of the flare laterals downstream of BDV10 (RTD 44 and RTD 26), measurements and predictions are generally consistent with a discrepancy of ±5 K. The reason why the uncertainty is higher than the usual ±3 K probably arises from:

- the complexity of platform C leading to rather strong assumptions in the modelling;
- the overall thermal response time of each (relatively massive) RTD assembly, which is at least 20 s: thus there is unlikely to be good correspondence between measured and predicted temperatures over time–scales of less than 20 s and perhaps as much as 60 s;
- siting of some RTDs at or near expansions, tees and bends which can give somewhat misleading information because flow recovery, that is re–establishment of locally fully–developed velocity and temperature profiles in the fluid flowing in the line(s), takes place over an axial distance of order 40 pipe diameters for a one–phase turbulent flow and longer for a two–phase (gas plus suspended liquid droplets) turbulent flow since there is considerable slip between the phases: thus there are local effects leading to steep axial temperature gradients which are not accounted for in BLOWDOWN.

4.5.2 *Choked expansions and supersonic flow*

Although there is bad agreement between predicted and measured outside wall temperatures on the flare laterals downstream of BDV10 (RTD 44 and RTD 26), there is good agreement immediately upstream (RTD 20 and RTD 21). This suggests that BLOWDOWN predictions of the temperature of the gas entering BDV10 and, more importantly, of the gas leaving the line immediately downstream of BDV10 are reliable. Moreover, the length–to–diameter ratio of the line immediately downstream of BDV10 (and upstream of the sites of RTD 44 and RTD 26) is a little over 150 so that the flow leaving that line should be locally fully–developed and hence BLOWDOWN predictions of the temperature of the gas leaving that line should be reliable. But the flow at the end of that line is choked throughout most of the blowdown. Experimental evidence from a variety of sources (including platform B) shows that the flow downstream of an expansion, that is a junction between an upstream line and a downstream line of larger diameter, can be very much colder (even after allowing for Joule–Thomson expansion) when the flow in the expansion is choked than when it is unchoked. As a result, the pipework downstream of the expansion can also be considerably colder. Indeed, it appears that the flow can become supersonic in the pipework downstream of a choked expansion and the axial distance between the choked expansion and the downstream shock transition to subsonic flow can be several hundred pipe diameters. For a large flare or vent line, this may involve an axial distance of order 100 m. In order for a flow in a flare or vent line downstream of a blowdown valve or restriction orifice to be supersonic, there must inevitably be conversion mainly of thermal energy into kinetic energy: there cannot be much conversion of pressure energy into kinetic energy because the flow in a line downstream of a valve or orifice is already at low pressure. Thus supersonic flow in a line downstream of such a valve or orifice is inevitably very cold and the supersonic flow appears to persist for a great distance (even round bends and through tees), with obvious consequences for the minimum design temperatures of flare and vent systems. It should, however, be noted that such supersonic flow is relatively rare. Thus, on platform C, it arises only downstream of BDV10 though choked pipework occurs downstream of some of the other BDVs too. It appears that supersonic flows occur only under a relatively restricted set of circumstances, specifically when there is choking at an expansion between an upstream line of given diameter and a downstream line of only slightly larger diameter. Presumably, supersonic flow might also arise downstream of an orifice only slightly smaller than the line immediately downstream.

4.5.3 *Back–pressure*

Case studies undertaken on platform C reveal the crucial effect of back–pressure on minimum temperatures in flare and vent systems. Minimum wall temperatures would be about 20 K lower if only one train of platform C were to be blown down instead of three. The reason is that much lower flow rates would lead to much lower back–pressures downstream of the blowdown valves which would in turn permit much more expansion and hence much more cooling to occur. Similarly, minimum wall temperatures would be up to about 40 K higher if a wellhead were to be blown down at the same time as the three trains, the export manifold and the reinjection system. The reason is now that much higher flow rates would lead to much higher back–pressures which would in turn permit much less expansion and hence much less cooling to occur. The obvious implication is that a well might be left flowing during a blowdown so as to avoid low temperatures within a flare or vent system. (The only problem that is likely to arise is the increased flow rate to flare or vent. For a flare, this peak flow rate might give rise to a very large flame and hence may cause damage to the flare itself or cause unacceptably high radiation levels to personnel or equipment.) The more important implication is that blowdown of a complete installation does not necessarily represent the worst case: the lowest back–pressures and hence the lowest fluid and wall temperatures in the flare or vent system often arise when only a small part of the installation is blown down.

4.6 Gas treatment plant

Experimental measurements have been made on an onshore gas treatment plant comprising an inlet gas receiver system and then two parallel separation and stabilisation trains. Two consecutive blowdowns were performed. The first was of one of the trains (Train 2: Train 1 was not operational at the time) and is not discussed here. The second was of the inlet gas receiver system and is discussed in what follows. The inlet gas receiver system comprises:

- an Inlet Gas Receiver (IGR),

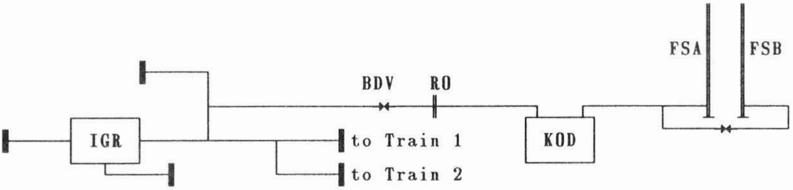
together with very significant quantities of piping. There is blowdown through one blowdown valve (BDV) and restriction orifice (RO) to:

- a Knock–Out Drum (KOD),

and then to:

- two parallel Flare Stacks (FSA and FSB),

the larger of which (FSB) operates only when the pressure in the KOD exceeds a pre–set value.



Comparisons of measurements with predictions made using BLOWDOWN are summarised in Figures 2a–l. Solid lines refer to measurements (made using either meters already installed on the plant or specially–mounted thermocouples (TCs) on the outside surfaces of vessels and lines) and broken lines to predictions.

4.6.1 *Predictions and measurements*

- Figure 2a is for meter P1 sited in the feed line to the IGR: there is very close agreement between the predicted and measured pressures. The only slight disagreement occurs shortly after the start of the blowdown and is associated with the onset of two–phase (gas–plus–liquid) flow in the originally one–phase (dense–phase or supercritical) system: the phase change (indicated by the change in slope of the pressure–time curve) is predicted to occur at a rather higher pressure than the measurements indicate. This may suggest a slight error in the thermodynamic model in BLOWDOWN or a slight error in the measured initial composition of the hydrocarbon or both.
- Figure 2b shows that there is close agreement between predicted and measured bulk fluid temperatures in the feed line to the IGR (TC1). The slight discrepancy may arise because the thermal response time of the thermowell housing thermocouple TC1 (given to an order of magnitude by the square of its radius divided by its thermal diffusivity) is likely to be of order a few minutes so that the measured temperature lags the predicted temperature by a few minutes, as observed.
- Figure 2c shows that there is close agreement between predicted and measured outside wall temperatures in the feed line to the IGR (TC2).
- Figure 2d shows that there is reasonable agreement between predicted and measured outside wall temperatures in the condensate line from the IGR (TC3). The small but consistent disagreement may again be associated with a slight error in the thermodynamic model in BLOWDOWN or a slight error in the measured initial composition of the hydrocarbon in the inlet gas receiver system or both. This would lead in turn to a slight error in the predicted bubble point temperature of the condensate which forms in and almost completely fills the line and hence to a slight error in the predicted temperature of the wall of the line.
- Figure 2e shows that there is close agreement between predicted and measured outside wall temperatures of the IGR (TC4, TC5 and TC6 located at increasing heights above the base of the IGR). The best agreement is obtained with the measurements made using thermocouple TC4, perhaps because the wall by thermocouple TC4 is always in contact with condensate. In contrast, the wall by thermocouples TC5 and TC6 is in contact with gas for most of the blowdown (after a short initial period in which it is in contact with dense–phase fluid and then a longer one when it is contact with condensate).
- Figure 2f shows that there is close agreement between predicted and measured outside wall temperatures in the line from the IGR (TC7 and TC8). The better agreement is obtained with the measurements made using thermocouple TC8, perhaps because the flow is undeveloped at the tee on which thermocouple TC7 is mounted.
- Figure 2g shows that there is close agreement between predicted and measured outside wall temperatures in the line by the block valve to Train 1 (TC9). The predicted temperature varies less than the measured one probably because the former is essentially that of the outside of the block valve to Train 1, the thermal mass of which is large, whereas the latter was measured a very small distance away from the block

valve on a line of considerably less thermal mass.

- Figure 2h shows that there is adequate agreement between predicted and measured outside wall temperatures in the line by the reducer to the line to the isolation valve to Train 2 (TC10). The agreement is less good than usual perhaps because the thermocouple is immediately above the reducer and the line immediately below the reducer and the reducer itself are almost full of much colder condensate for most of the time.
- Figure 2i shows that there is close agreement between predicted and measured outside wall temperatures in the line to the BDV and RO (TC11).
- Figure 2j shows that there is poor agreement between predicted and measured outside wall temperatures immediately downstream of the RO (TC12). The reason for this disagreement is perhaps the location of the thermocouple on the (short) expander from the outlet flange from the RO to the inlet flange to the line downstream. Thus flow in the expander is almost certainly undeveloped. The thermocouple is, moreover, on the top of the expander which is an eccentric one aligned at the bottom. Accordingly, the fluid in the expander by the thermocouple would probably not be in the jet–like flow from the RO. Finally, the large thermal mass of the flanges would probably increase the minimum wall temperature in the expander and also increase its thermal response time by of order a few minutes so that the measured temperature lags the predicted temperature by a few minutes, as observed.
- Figure 2k shows that there is close agreement between predicted and measured outside wall temperatures in the line downstream of the RO (TC13).
- Figure 2l shows that there is close agreement between predicted and measured outside wall temperatures in the line from the KOD (TC14). The agreement is surprisingly good considering that thermocouple TC14 was part of a hand–held probe: obtaining good thermal contact between the probe and the outside surface of the line is difficult: any lack of contact would mean that the probe would tend to over–estimate sub–ambient temperatures, as observed.

Comparison of predictions made using BLOWDOWN with measurements made during this test thus yields generally adequate agreement. Measurements and predictions are generally consistent with a discrepancy of ±6 K. The reason why the uncertainty is higher than the usual ±3 K probably arises from the complexity of the inlet gas receiver system and the siting of some TCs at or near expansions, tees and bends.

4.6.2 *Liquid collection*

Analysis of the BLOWDOWN predictions for the gas treatment plant reveals the crucial effect of liquid collection on minimum wall temperatures. The BLOWDOWN model of the inlet gas receiver system comprises thirty–six units. Most of these units represent sections of piping: so many are required because the piping is very extensive and there are many changes in orientation between vertical and horizontal. The hydrocarbon in the inlet gas receiver system is initially dense–phase. During blowdown, a very significant quantity of liquid is formed. The main mechanisms for heat transfer between liquid and a wall and gas and a wall are boiling and natural convection, respectively. As a result, heat transfer between liquid and a wall is very much better than that between gas and a wall. Thus the temperature of a wall by liquid is very similar to that of the liquid whereas the temperature of a wall by gas is generally often much higher than that of the gas. The result is that the collection of even small quantities of liquid can lead to localised cold walls. In the case of the inlet gas receiver system and, in particular, the line between the IGR and Train 2, which is very long indeed and in which there are many changes in orientation, there are low points where relatively small quantities of liquid collect. The minimum bulk gas temperature there is predicted to be about 239 K and the corresponding wall temperature to be about 279 K. The minimum bulk condensate temperature there is also predicted to be about 239 K but the corresponding wall temperature in contrast is predicted to be about 243 K. Thus, if liquid collection is allowed for, the minimum wall temperature is predicted to be over 30 K lower than if it is not. Failure to model liquid collection (in particular, liquid drainage) would mean that minimum temperatures would be seriously over–estimated.

4.6.3 *Upstream and downstream units*

Analysis of the BLOWDOWN predictions for the gas treatment plant also reveals the important effect on downstream units of upstream units blowing down through them. Thus when there is flow of cold hydrocarbon, usually gas perhaps with some suspended liquid droplets, from an upstream unit through a downstream unit which is already cold because it is itself being blown down, the downstream unit can get very cold indeed. Additional cooling of this sort accounts for up to about 10 K of the drop in wall temperature of some units in the inlet gas receiver system. It would account for much more if the upstream unit were much bigger, that is of much larger thermal mass, than the downstream one. Thus blowdown of a system comprising more than one vessel involves connectivity or coupling problems, failure to model which can lead to serious errors. These connectivity problems can be particularly acute when there are several blowdown valves. One common example is a compressor system, which is typically blown down upstream, by the inlet scrubber, and also downstream, by the aftercooler. (Other examples are to be found on platform C, where each train is blown down through three blowdown valves simultaneously and the reinjection system is blown down through two blowdown valves simultaneously.) BLOWDOWN is able to model all of these situations. One of the most complicated situations modelled so far is a wellhead manifold system comprising thirty–six wellheads, all linked to six headers (four production, one test and one flare), with blowdown through five blowdown valves to a knock–out drum and then to a flare stack. In addition to the topological complexity of this system, there is also very significant liquid drainage and collection, proper modelling of which is vital to making accurate predictions of minimum wall temperatures.

5 CONCLUSION

BLOWDOWN is based on very accurate thermodynamics and extensive use of appropriate correlations for heat transfer and fluid mechanics. The accuracy of the predictions made using BLOWDOWN stems from the accuracy of the thermodynamics and the appropriateness of the correlations: relaxation of either can lead to significant errors. Confidence in its predictions comes from its validation by comparison with experimental measurements, much at full–scale. As a result of this validation, some of which is described briefly here, BLOWDOWN can be and has been used by many oil and gas companies for the simulation of very many depressurisation systems.

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Figure 1a – P1

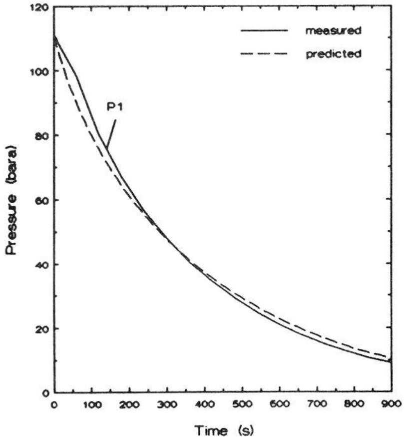


Figure 1b – P2

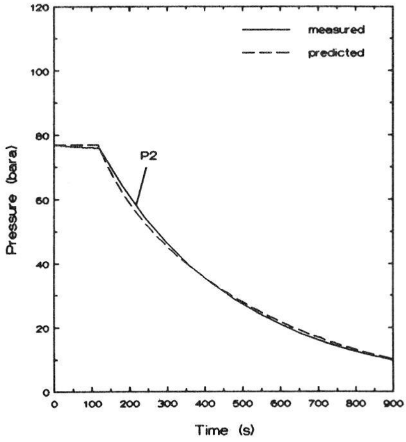


Figure 1c – RTD1/RTD4/RTD5

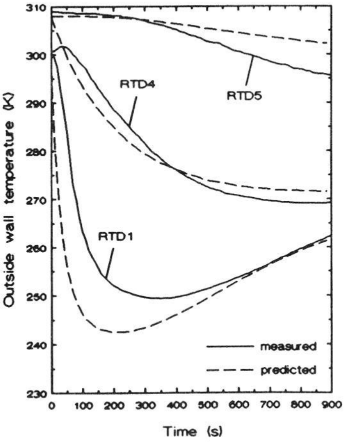


Figure 1d – RTD39/RTD40

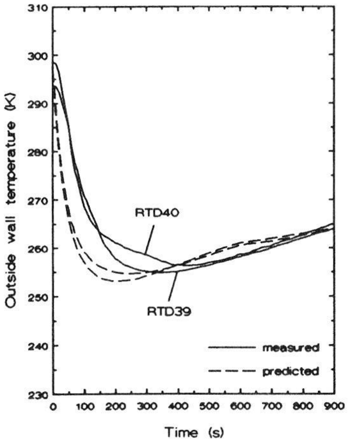


Figure 1e - RTD20/RTD21

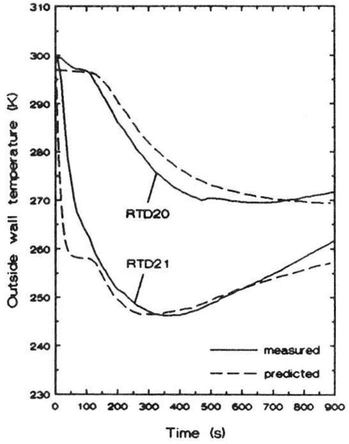


Figure 1f - RTD26/RTD44

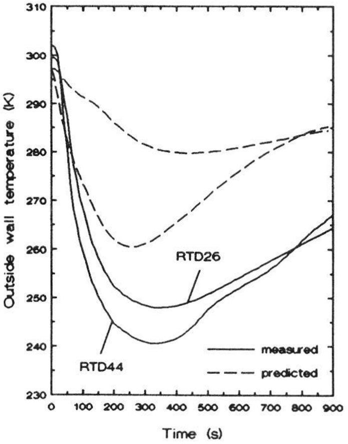


Figure 1g - RTD27

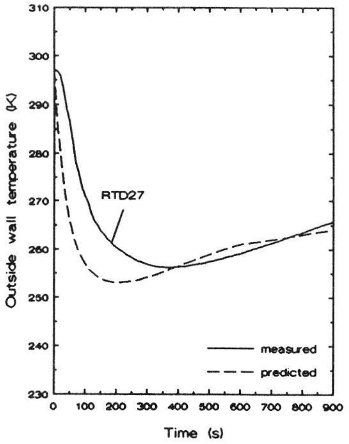


Figure 1h - RTD42/RTD43

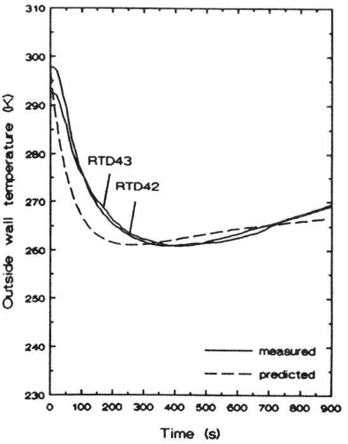


Figure 2a - P1

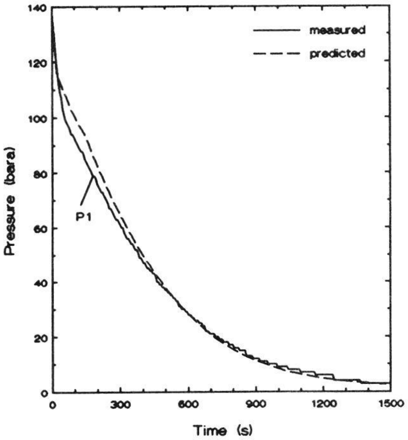


Figure 2b - TC1

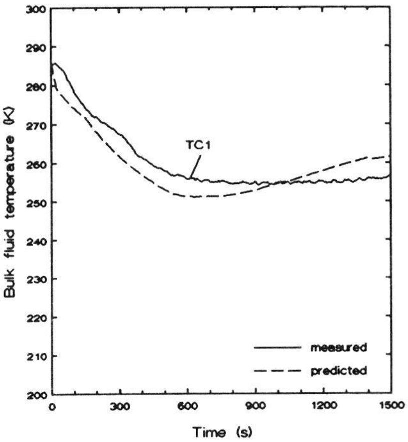


Figure 2c - TC2

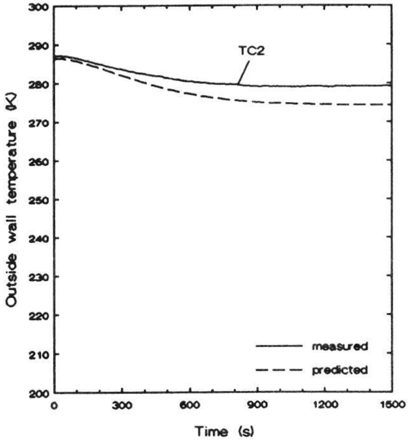


Figure 2d - TC3

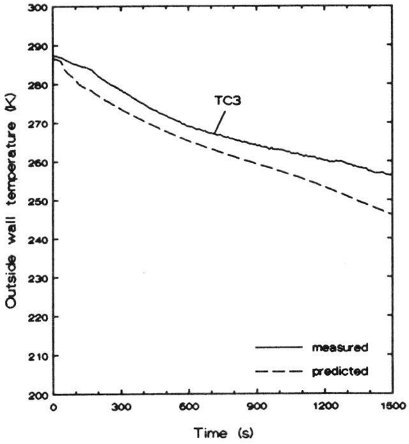


Figure 2e - TC4/TC5/TC6

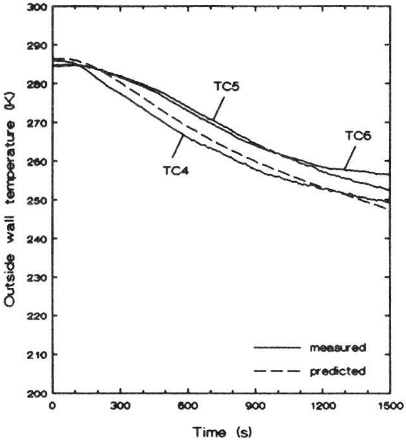


Figure 2f - TC7/TC8

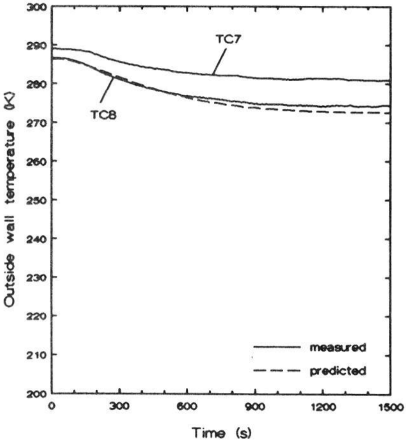


Figure 2g - TC9

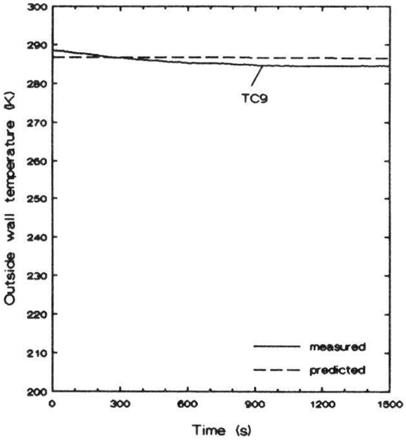
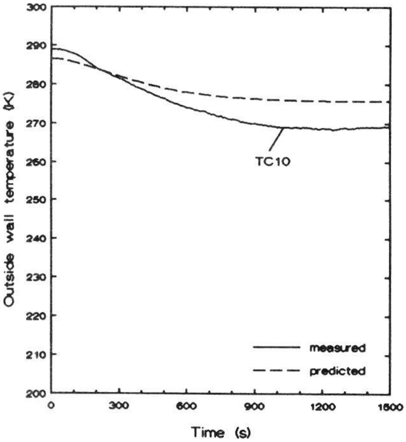


Figure 2h - TC10



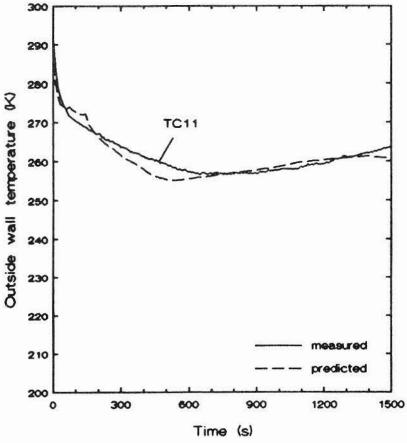


Figure 2i - TC11

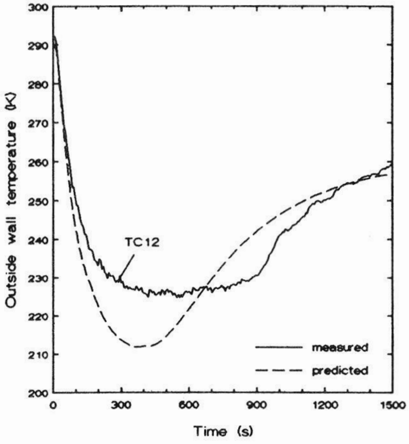


Figure 2j - TC12

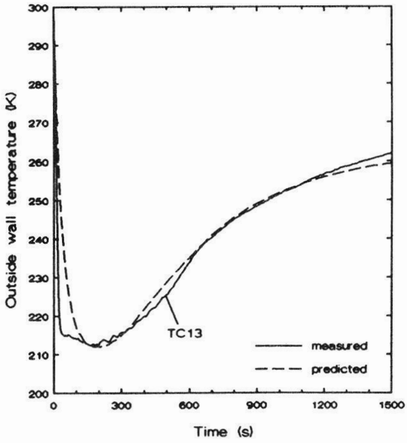


Figure 2k - TC13

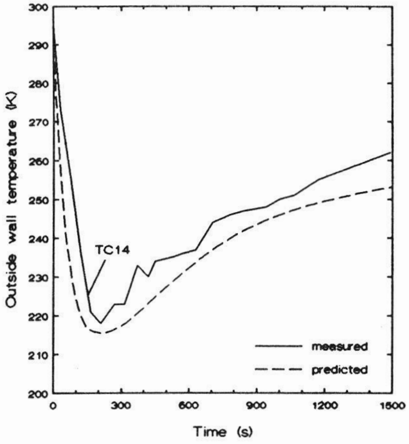


Figure 2l - TC14