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THE HONG KONG
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Study of Stack Pressure Change in High-rise Sewage System

Submitted by:

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Contents

Executive Summary

The rapid virus spread and the fact that most SARS infections occurred on floors above the super-spreader's floor in Amoy Garden have prompted investigations by the Government of the HKSAR and by a research team from the University of Hong Kong. As a result of these studies, a number of possibilities have been raised to explain the particular virus spreading mode, but it was believed that further study is necessary to find out if virus could move up the drainage pipe and by what means. The study was initiated and directed by Dr. Hon. Lui Ming Wah and supported by Dr. Chris H.C. Wong, Director of Industrial Centre of The Hong Kong Polytechnic University.

In order to evaluate the change of pressure in the stack (vertical main pipe) at different length of the branch pipe, ventilation condition of the stack and different sizes of the stack pipe, a scaled down model was constructed, and actual tests were carried out by members of the Building & Construction Unit of the Industrial Centre, The Hong Kong Polytechnic University in May & June 2003.

The method of tests was basically by means of pressure measurement at the junctions of branch pipe and the stack pipe, and at the bottom of the stack before a bend. Results are presented together with discussions and analysis.

There are totally thirty-six sets of graphs showing the pressure at the junctions of pipes and the bottom of the stack against the duration of discharge, further twelve curves showing the relationship between the pressure and the length of branch pipe at different sizes of stack pipe. It was observed that the pressure at the test points varied notably with the length of the branch pipes, diameter of the stack pipe, ventilation condition and down-flow of water. However, it should be noted that magnitude of pressure change at the T-junction was smaller for longer branch pipe or bigger stack pipe. Most important, there are negative or positive pressures at the T-junction and at the bottom. These may contribute to the upward movement of the foul air inside the stack pipe and its further spreading through the drainage system into bath rooms on the upper floors; that bring along the virus which causes SARS infection.

It was observed in the present study that amongst these variables, the length of the branch pipe is most critical to pressure drop at the T-junction and it should have a length which is commensurate with the volume of water discharged from the cistern and preferably have a gradient to the stack pipe. For the stack pipe, it should have a larger diameter than the branch pipe, so as to smooth out the flow at the T-junctions.

From the present findings, it is recommended that a critical review on the design and installation of branch pipes in the local high-rise sewage system should be conducted immediately to prevent virus spreading through it in the future.

1. Introduction

1.1. Objectives of Study

Whenever there is discharge from a toilet, soil water flows along the branch pipe to the T-junction then to the vertical stack, the stack pressure will vary as a result. The objectives of the study are:

- to simulate the process on two consecutive floors in a single stack system
- to identify the change of pressure in the stack during discharge
- to evaluate the change of pressure at different length of branch pipe connecting to the stack pipe.
- To identify the change of pressure in the stack of different pipe sizes.

1.2. Scope of Work

The scope of work in this project covers the following:

- To set up a scaled down model of a pipework system of 1 to 3; which includes a cistern, a branch pipe and a vertical stack with transparent plastic materials. Pressure sensors are installed at the T-junction and bottom of the stack respectively to record the real time pressure.

- A general evaluation of the stack pressure variation with respect to the boundary conditions namely blockage of stack, down flow of water in the stack, the length of branch pipe, and the sizes of the stack pipe, by taking measurements of pressure in different combination of the boundary conditions.

- To observe the flow of fume inside the stack while there is a down flow of water in the stack and ventilation is blocked.

2. Methodology

2.1 Modelling of sewage pipe system for test

A scaled down model of the sewage pipe system was set up with reference to the as-built information of the Amoy Garden in Ngau Tau Kok District, Kowloon. It was used to simulate the simplified main features of the above-ground drainage pipe work common in local high-rise buildings. The building information was provided by the Building Department as below:

- Floor to floor height: 2.65 m
- Minimum 9L of water in each discharge

- Branch pipe: 100mm Φ.
- Stack pipes size: 150mm Φ from G/F to 4/F, 100mm Φ above 4/F

Water discharge to the stack is controlled by a ball valve, it flushes from a cistern along the branch drain pipe to a T-junction and then flows into the stack; two pressure sensors are installed at the T-junction and at the bottom before the bend of the stack pipe respectively to record the real time pressure (reading up to 0.1kPa). To evaluate the effect of different lengths of branch pipe, three lengths were chosen for the tests including 1D (length = 1 diameter), 3D and 38D (length = volume of water / pipe cross-sectional area). With a scale of about 1:3, the length of branch pipes are 30mm, 90mm and 1160mm respectively. The diameters of the stack in the test are (a) 100mm Φ only, (b) 100mm with 150mm Φ and (c) 150mm Φ respectively. The basic set-up of the model is shown in Figure 2.1, 2.2 & 2.3.

Main features of the pipe system model: -

Cistern - 0.82 litre

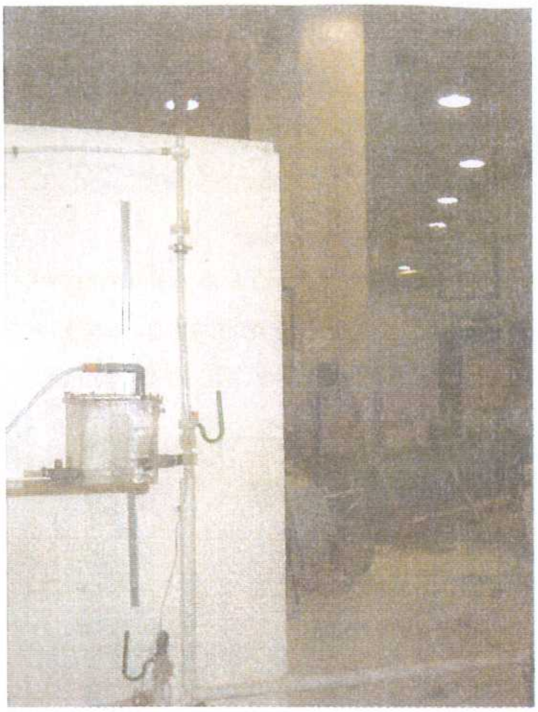
Branch pipe - D, 3D & 38D

Stack pipe - vented /un-vented
(100mm Φ / 150mm Φ)

Pressure sensors (2 nos.)

Fig. 2.1

The sewage pipe work system model with stack of 100mm Φ for upper and lower zone; the branch pipe of 3D long



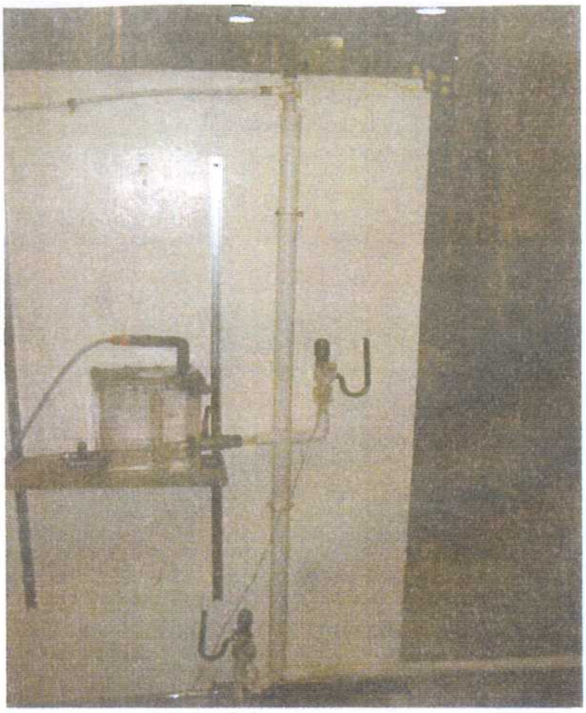


Fig. 2.2

The sewage pipe work system model with stack of 100mm Φ at the upper zone 150mm Φ at the lower zone ; the branch pipe of 1D long

Fig. 2.3

The sewage pipe work system model with 150mm Φ for upper and lower zone; the branch pipe of 3D long

2.2 Determination of volume of water for test

In order to simulate the flow condition, it is necessary to derive a reasonable "scaled down" volume of water with respect to the prescribed ratio of 1:3

The amount of water required was estimated as follows:

$$\frac{V.\,\pi\,(100)^2}{4} = \frac{V.\,\pi\,(30)^2}{4}\,.\,f$$

It gives $f = 11$

For $Q = 9$ litre,

With $Q = Q'f$, then $Q' = 0.82$ litre (volume of water to be used in the tests)

Where:

Q = cistern water capacity for flushing in true scale

Q' = scaled flushing capacity in the model

V = velocity of flushing

f = scale factor

2.3 Discharge Test

A series of water flow tests was carried out using different length of branch pipe and in different boundary conditions:

2.3.1 Different lengths of branch pipe

As described in section 2.1, three lengths were chosen for the tests including 1D, 3D and 38D; the set-up of 38D branch pipe is illustrated in Fig. 2.4.

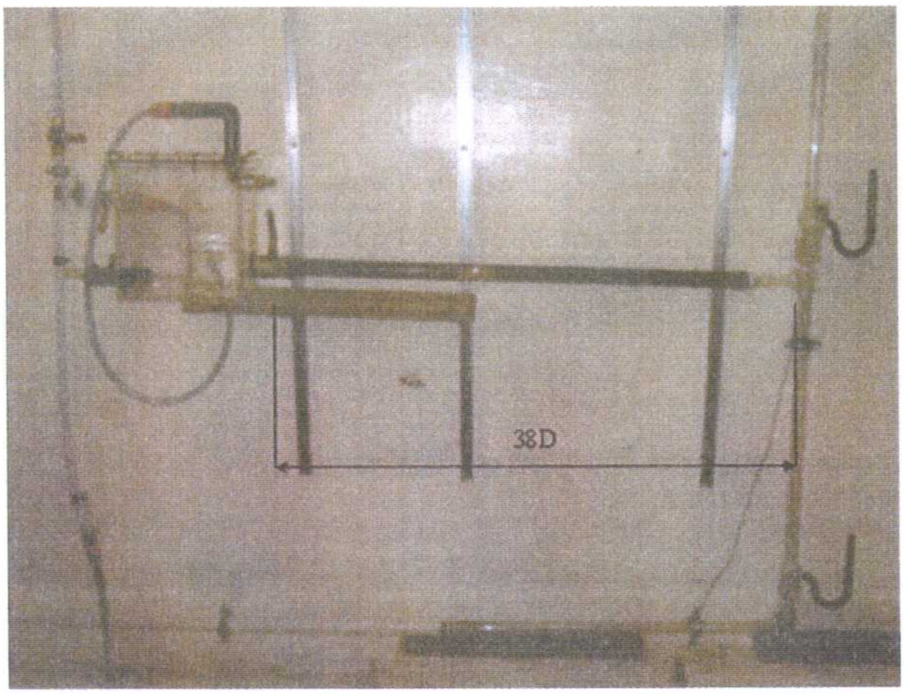


Fig. 2.4

The sewage pipe work system model with the branch pipe of 38D long

2.3.2 Vent pipe conditions

- Through vent pipe condition - top end of the stack is opened
- Blocked vent pipe condition - top end of the stack is blocked

2.3.3 Water down flow from upper zone to simulate water flowing from the upper floors

- With water flow from upper zone of stack
- Without water flow from upper zone of stack

2.4 Smoke Test

Smoke was injected into the pipe at the lower T-junction of the stack pipe. The test is to see the smoke flow pattern inside the stack.

3. Procedures & Results

3.1 Procedures

1) Install two pressure sensors properly at the locations as mentioned in section 2.1
2) Fill up 0.82 litre of water to the cistern
3) Open the ball valve to drain water into the pipework system
4) At the same time of opening of the ball valve, start the video camera to capture the readings of pressure senor and the water flow
5) Download the video clips of the test to computer
6) Take record of the captured pressure data per 0.25 sec. by means of "Windows Media Player"
7) Enter the data in an "Excel" format and plot the corresponding graphs using "Pressure (kPa) vs. Time (sec)".
8) Carry out analysis of the test results on the graphs
9) Repeat the test using different lengths of gradient drain pipe of D, 3D & 38D in different combinations of ventilation and down flow of water in the stack.
10) Conduct three sets of tests by repeating step 1) to step 9) above using different diameter of stacks i.e.
    - 100mm Φ at upper and lower zone
    - 100mm Φ at upper zone and 150 mm Φ at lower zone
    - 150mm Φ at upper and lower zone

3.2 Result of Tests

There are totally 36 cases of readings taken in the three set of pressure tests using 3 sets of stack diameter as described in the item 10) of section 3.1 above. All the data of the test results are complied in a spread-sheet, the summary of the results are shown in the Appendix 1, 2 and 3; and the cases are numbered as "Case 1.1, 1.2, ... to Case 3.11, 3.12" respectively.

The 36 cases of pressure reading resulted from different combination of the boundary conditions and pipe sizes are tabulated as below:

Ventilation	Down-flow	Length of Branch Pipe in terms of diameter	Stack Diameter (mm)	Case No. in Appendix 1,2,3
Vented	No	1D	100	1.1
Vented	No	3D	100	1.2
Vented	No	38D	100	1.3
Vented	Yes	1D	100	1.4
Vented	Yes	3D	100	1.5
Vented	Yes	38D	100	1.6
Un-vented	No	1D	100	1.7
Un-vented	No	3D	100	1.8
Un-vented	No	38D	100	1.9
Un-vented	Yes	1D	100	1.10
Un-vented	Yes	3D	100	1.11
Un-vented	Yes	38D	100	1.12
Vented	No	1D	100x150	2.1
Vented	No	3D	100x150	2.2
Vented	No	38D	100x150	2.3
Vented	Yes	1D	100x150	2.4
Vented	Yes	3D	100x150	2.5
Vented	Yes	38D	100x150	2.6
Un-vented	No	1D	100x150	2.7
Un-vented	No	3D	100x150	2.8
Un-vented	No	38D	100x150	2.9
Un-vented	Yes	1D	100x150	2.10
Un-vented	Yes	3D	100x150	2.11
Un-vented	Yes	38D	100x150	2.12
Vented	No	1D	150	3.1
Vented	No	3D	150	3.2
Vented	No	38D	150	3.3
Vented	Yes	1D	150	3.4
Vented	Yes	3D	150	3.5
Vented	Yes	38D	150	3.6
Un-vented	No	1D	150	3.7
Un-vented	No	3D	150	3.8
Un-vented	No	38D	150	3.9
Un-vented	Yes	1D	150	3.10
Un-vented	Yes	3D	150	3.11
Un-vented	Yes	38D	150	3.12

In addition to the above 36 sets of data, in order to investigate the change of pressure at the T-junction of the stack and branch pipe, the maximum values of pressure at the junction are further plotted against branch pipe length with respect to different boundary conditions. With these maximum pressure values extracted from the 36 curves above, 12 curves are plotted and consolidated into four charts as shown in Appendix 4. The curves serve to outline the relationship between pressure change at the T-junction and branch pipe lengths at different sizes of stack. The boundary conditions in the tests are tabulated below for easy reference.

Ventilation	Down-flow	Stack Diameter (mm)	Chart No. in Appendix 4
Vented	No	100	4.1
Vented	No	100x150	4.1
Vented	No	150	4.1
Vented	Yes	100	4.2
Vented	Yes	100x150	4.2
Vented	Yes	150	4.2
Un-vented	No	100	4.3
Un-vented	No	100x150	4.3
Un-vented	No	150	4.3
Un-vented	Yes	100	4.4
Un-vented	Yes	100x150	4.4
Un-vented	Yes	150	4.4

4. Observations & discussions

4.1. Pressure Change

In the book by Wise & Swaffield (2002), the pressure distribution along a stack varies when there is discharge at the branches; there will be positive pressure at the bend of pipe at the base end. Similar phenomena were observed in the present tests, whilst pressure at the two levels of branch pipes varied and fluctuated when the branch pipe was discharging in different boundary conditions and with different stack sizes.

- When down-flow exists in the stack, negative pressure is observed in the T-junction, and positive pressure at the bottom end of the stack. The magnitude of change of pressure at the T-junction and the bottom increases with down-flow in the stack.

- Ventilation in stack pipe is a critical factor. When the stack pipe is covered; it will give rise to a higher negative pressure at the upper zone and a higher positive pressure at the bottom end of the stack. To reach equilibrium, positive pressure at the bottom pushes air upward to the T-junction where the negative pressure is lower.

- Pressure variation due to offset of diameter of stack is quite obvious, in particular when stack is 100mm Φ; ventilation blocked and branch pipe is short. It gives greater rise to the pressure difference as shown in Case 3.4 & Case 3.5 in Appendix 1.

- The head of flushing water is another factor affecting the pressure distribution. The cistern discharge of 9L of water was adapted in the test. If light accessories (American Standard) are used, effective discharge would increase to 12L; then the magnitude of pressure change in the test would be greater.

- In all cases, the pressure at the T-junction decreases with the increase of branch pipe length, i.e. longer the branch pipe, lesser the pressure change.

- In general, with the same condition of ventilation and down-flow, the pressure at the T-junction drops rapidly in case of 100mm Φ stack while it changes moderately in case of 150mm Φ stack.

- Branch pipe of length 1D causes a disturbance at the T-junction and a drop in pressure.

- Branch pipe of length 38D causes only small disturbance and little pressure change.

- The length of the branch pipe affects the change of pressure substantially. The magnitude of pressure difference between two levels of pipe junctions is smaller in cases of a branch pipe of 38D, i.e. the pressure gradient is not as high as the short branch pipe whereas Wise & Swaffield (2002) defined pressure gradient is the rate of change of pressure with distance.

4.2. Smoke Test

- No significant result was observed in the smoke test due to the limitation of the small scaled testing set-up. Anyway, when the vent pipe was covered (in un-vented condition), smoke was found to be trapped inside the stack for a longer period of time.

5. Conclusion

Despite the simple test equipment used, the study has shown that there are significant pressure variations inside the stack pipe. The lower pressure zone at the T-junction and the higher pressure zone near the bottom bend may act as driving force which causes the upward movement of foul air and virus-laden fine water droplets to the upper floors. This may explain why most infections have occurred near and above the floor where the super spreader has stayed.

The investigation has also demonstrated that the pressure rise or drop at the T-junction inside the stack pipe are affected by the boundary conditions, namely the size of the branch pipe and stack pipe, length of branch pipe, ventilation condition of the stack pipe and whether there is water down fall from upper floors. Amongst these variables, the length of the branch pipe is most critical to pressure drop at the T-junction, and it should have a length which is commensurate with the volume of water discharged from the cistern and preferably have a gradient to the stack pipe. For the stack pipe, it should have a larger diameter than the branch pipe, so as to smooth out the flow at the T-junctions.

From the present findings, it is recommended that a critical review on the design and installation of branch pipes in the local high-rise sewage system should be conducted immediately to prevent virus spreading through it in the future.

References

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4. HKSAR, (2003), Press Release, *Amoy Gardens investigation findings make public* [Online], Available from: http://www.info.gov.hk/gia/general/200304/17/0417247.htm [Accessed 9 June 2003]
5. HKSAR, (1997), CAP 123I Building (Standards of Sanitary Fitments, Plumbing, Drainage Works and Latrines) Regulations, [Online], Available from: http://www.justice.gov.hk/Home.htm [Accessed 30 June 2003]

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Disclaimer

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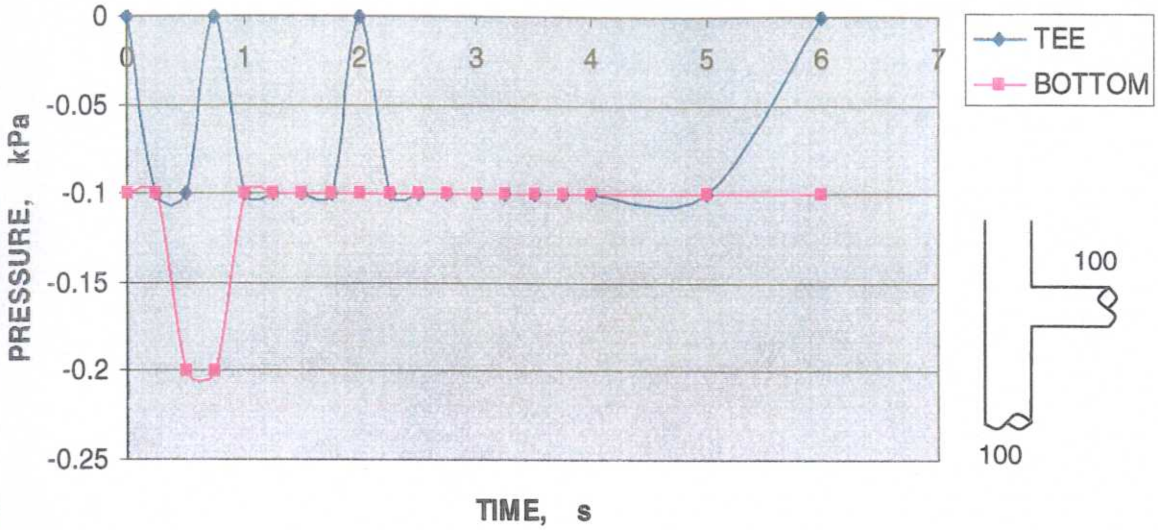
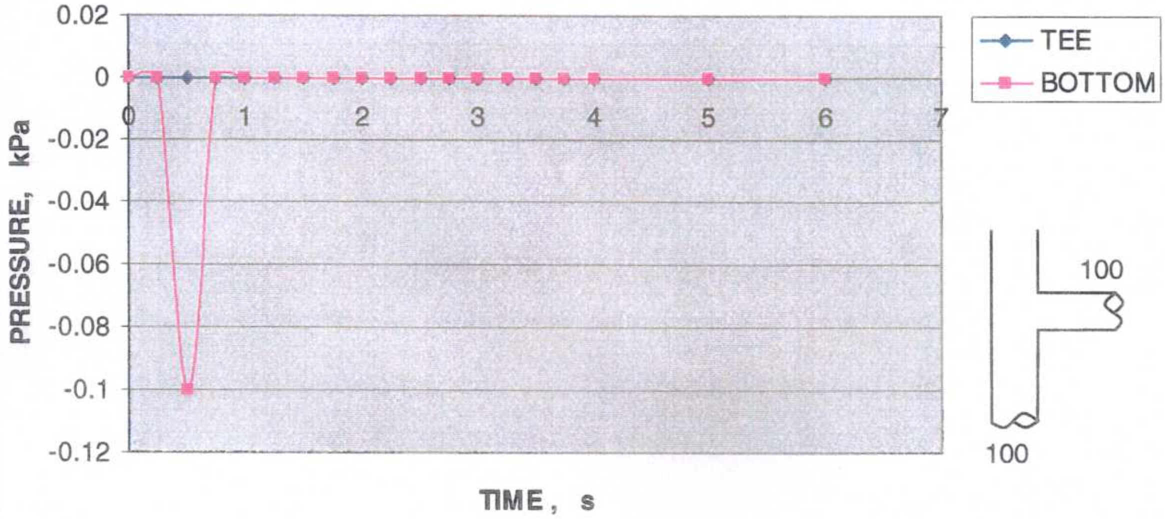
Appendices

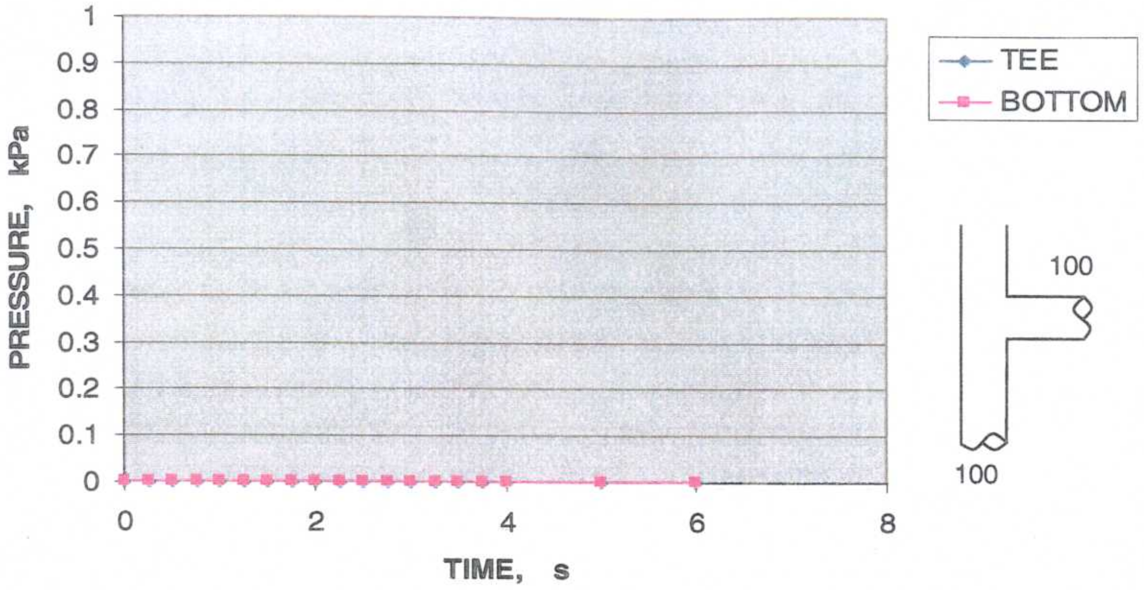
Appendix 1: Results of Test 1 (100 stack)



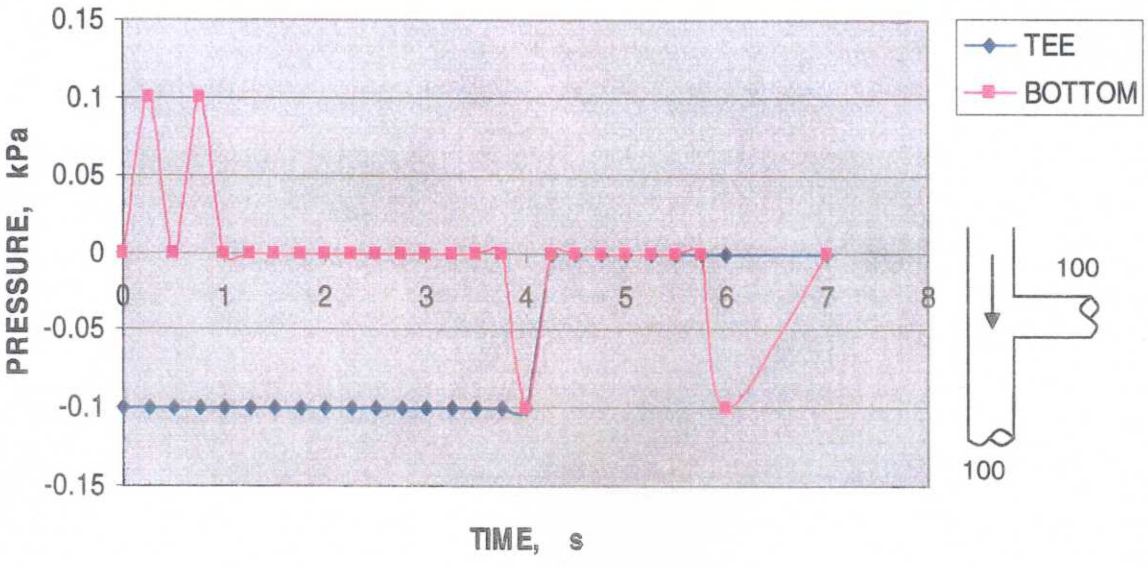
Case 1.1 Stack Pressure (vent, no downflow, branch pipe length = 1D)



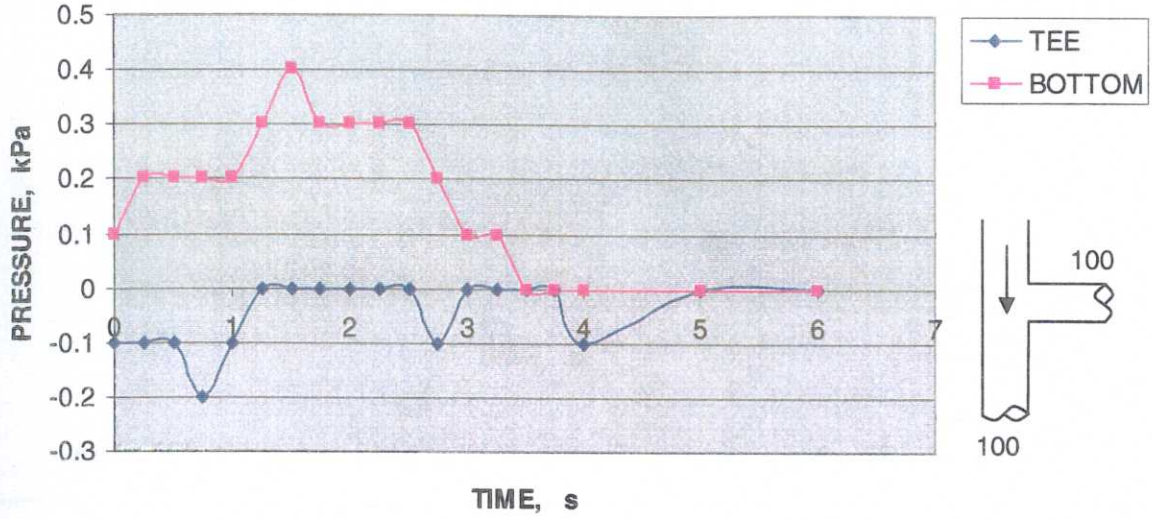
Case 1.2 Stack Pressure (vent, no downflow, branch pipe length = 3D)



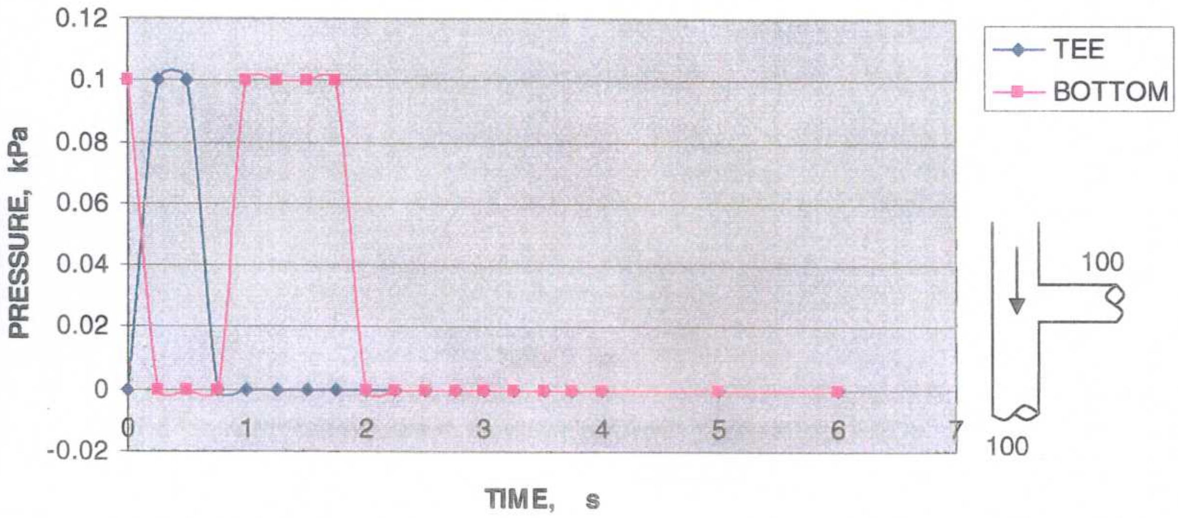
Case 1.3 Stack Pressure (vent, no downflow, branch pipe length = 38D)



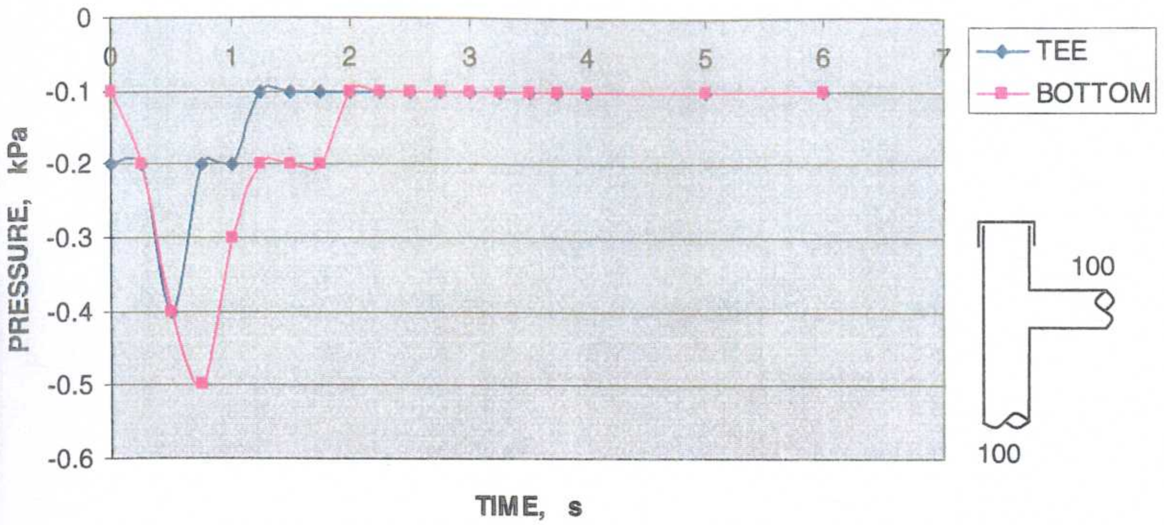
Case 1.4 Stack Pressure (vent, downflow, branch pipe length = 1D)



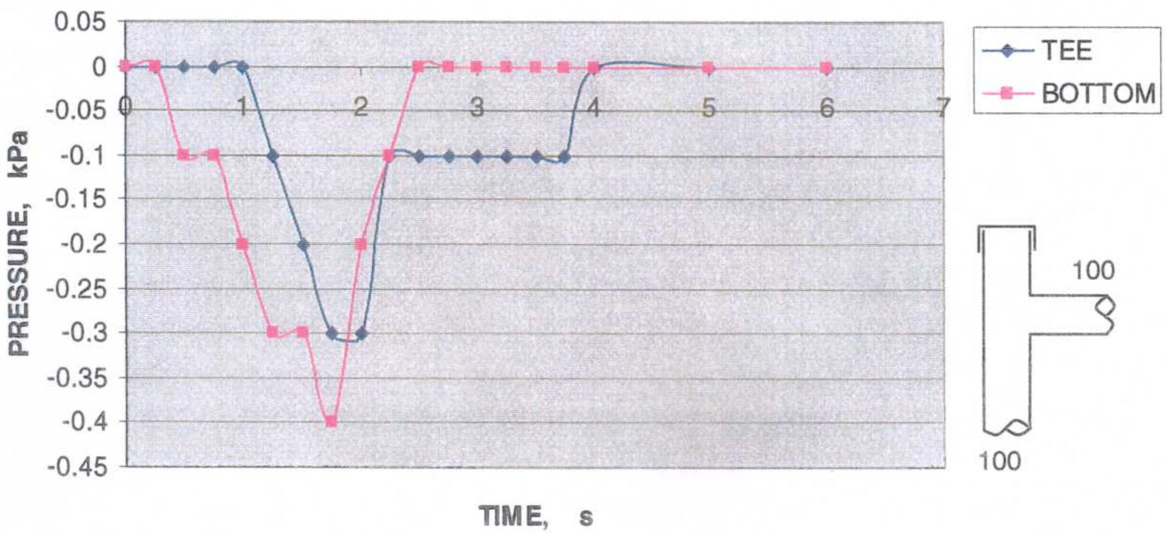
Case 1.5 Stack Pressure (vent, downflow, branch pipe length = 3D)



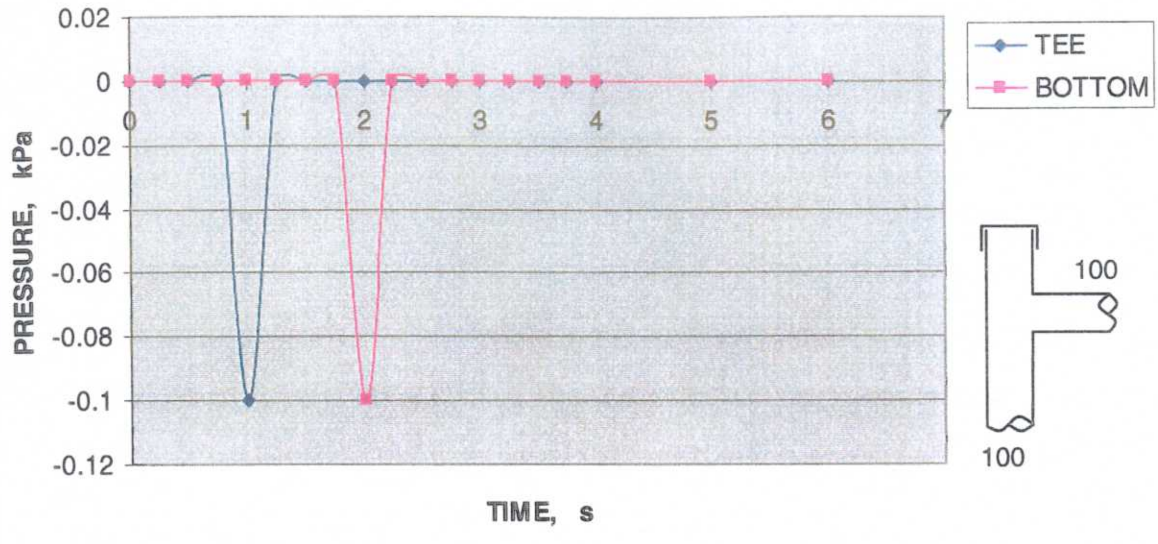
Case 1.6 Stack Pressure (vent, downflow, branch pipe length = 38D)



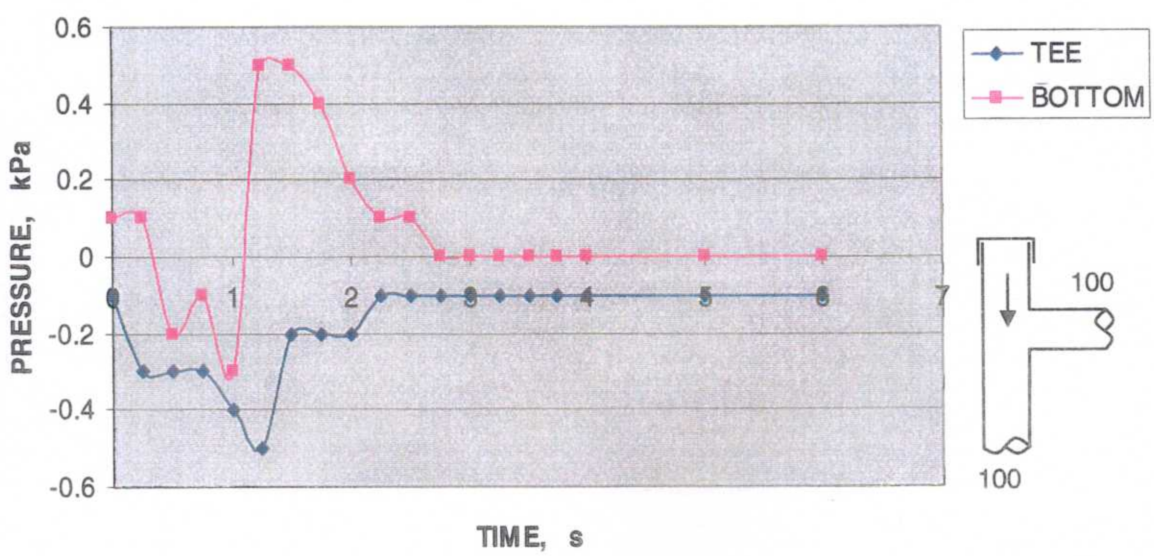
Case 1.7 Stack Pressure (unvent, no downflow, branch pipe length = 1D)



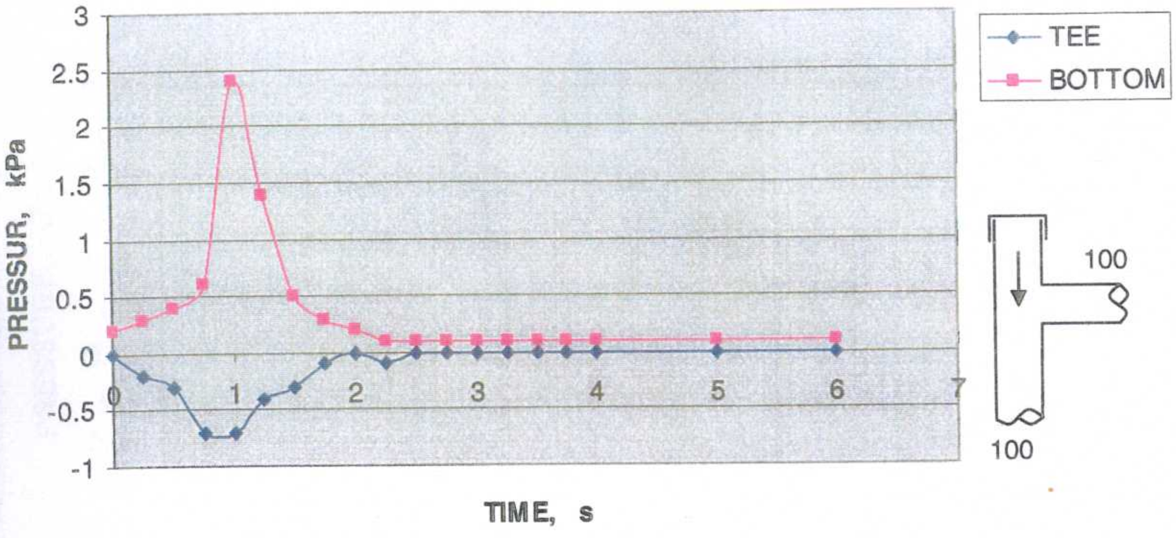
Case 1.8 Stack Pressure (unvent, no downflow, branch pipe length = 3D)



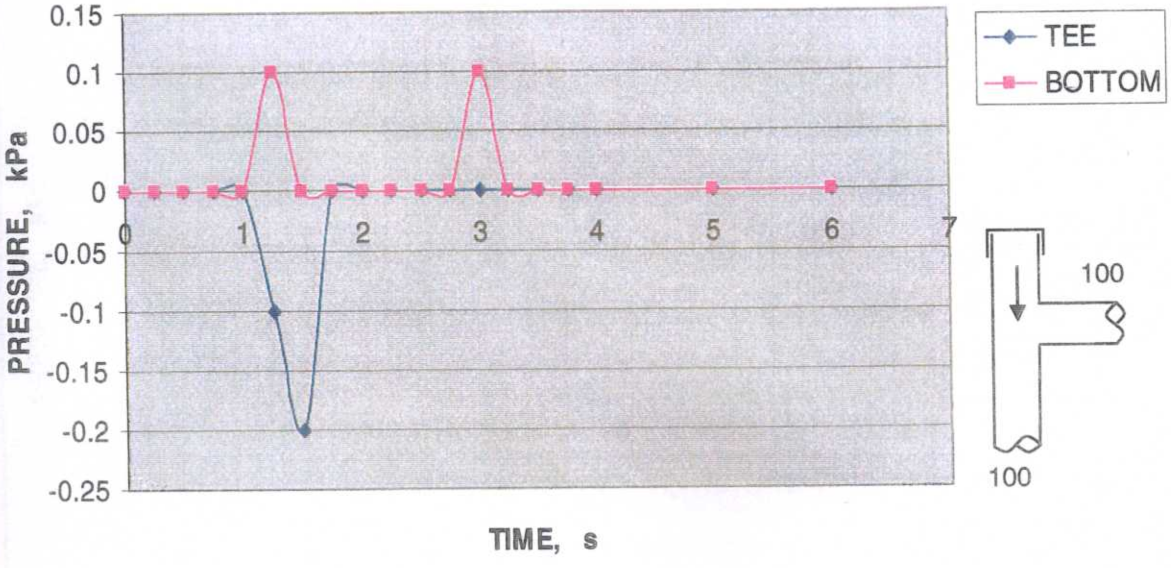
Case 1.9 Stack Pressure (unvent, no downflow, branch pipe length = 38D)



Case 1.10 Stack Pressure (unvent, downflow, branch pipe length = 1D)

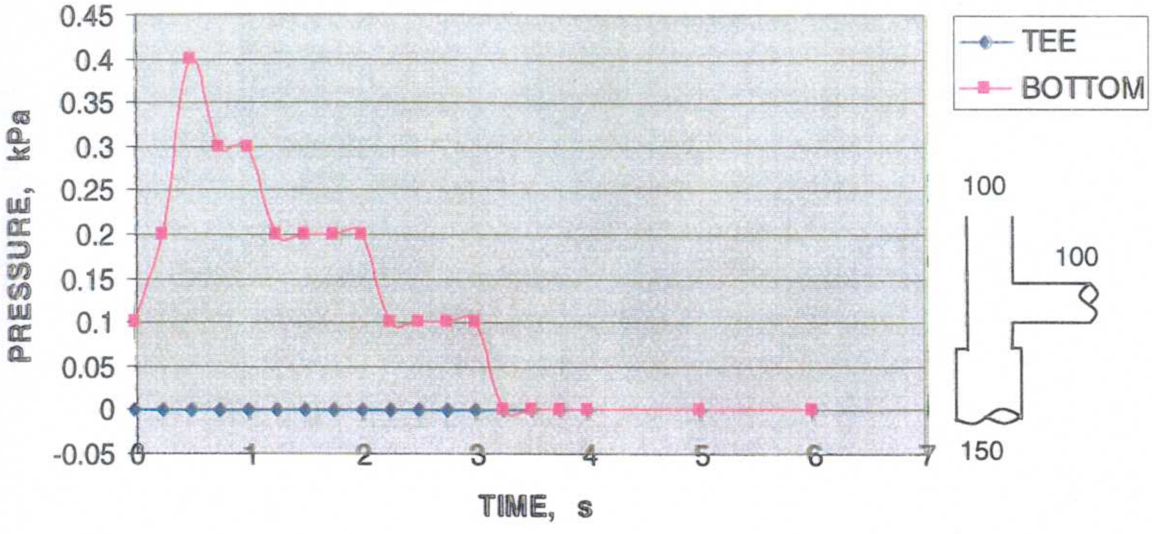


Case 1.11 Stack Pressure (unvent, downflow, branch pipe length = 3D)

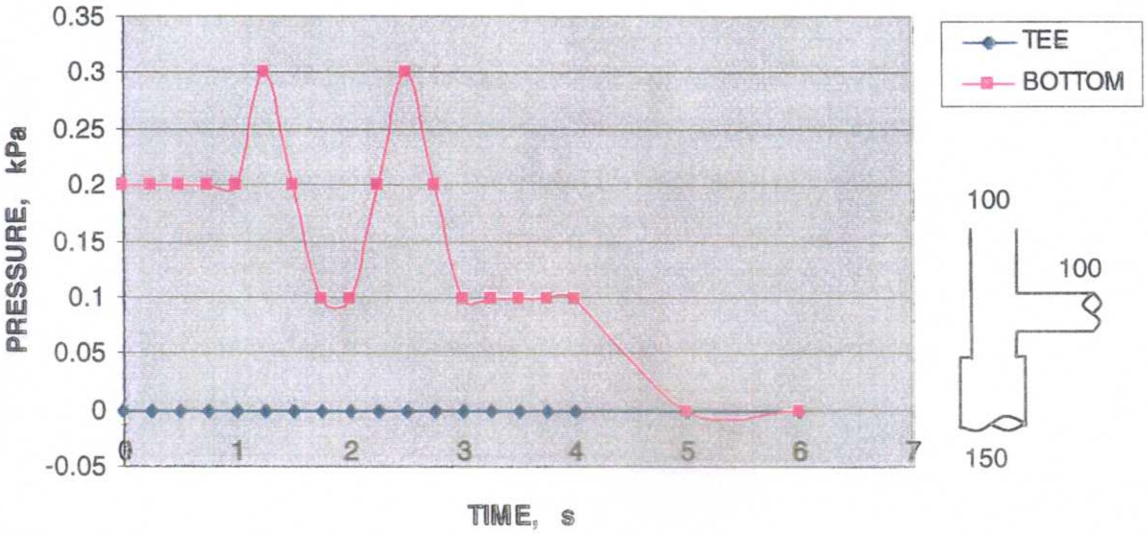


Case 1.12 Stack Pressure (unvent, downflow, branch pipe length = 38D)

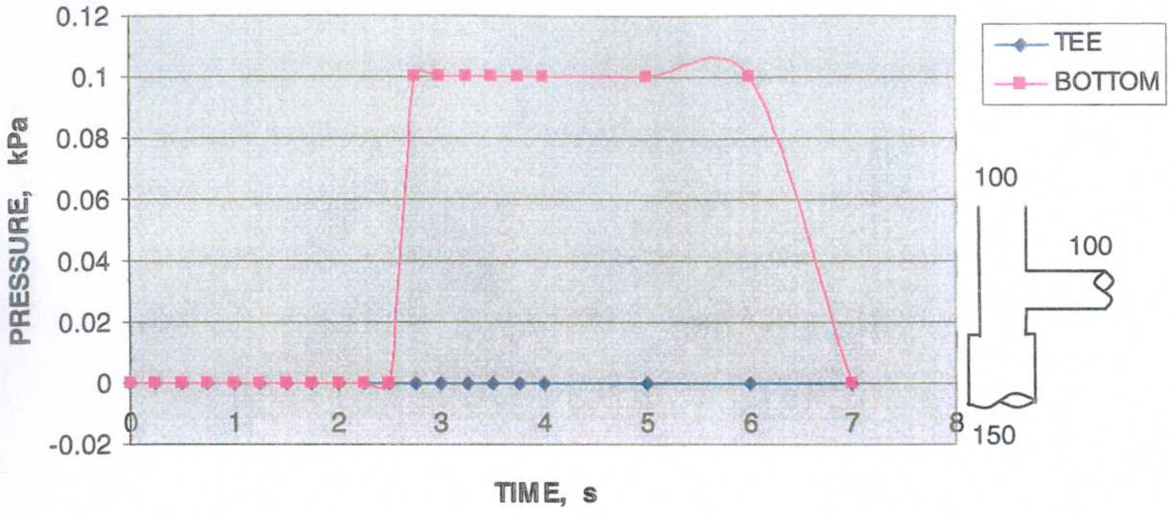
Appendix 2: Results of Test 2 (100x150 stack)



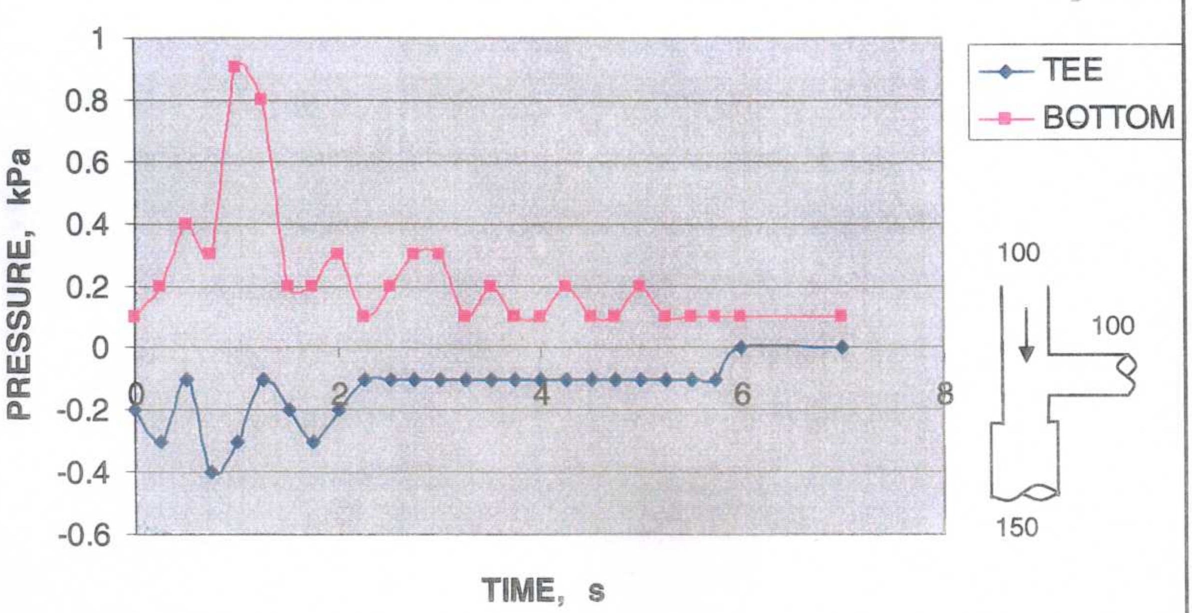
Case 2.1 Stack Pressure (vent, no downflow, branch pipe length = 1D)



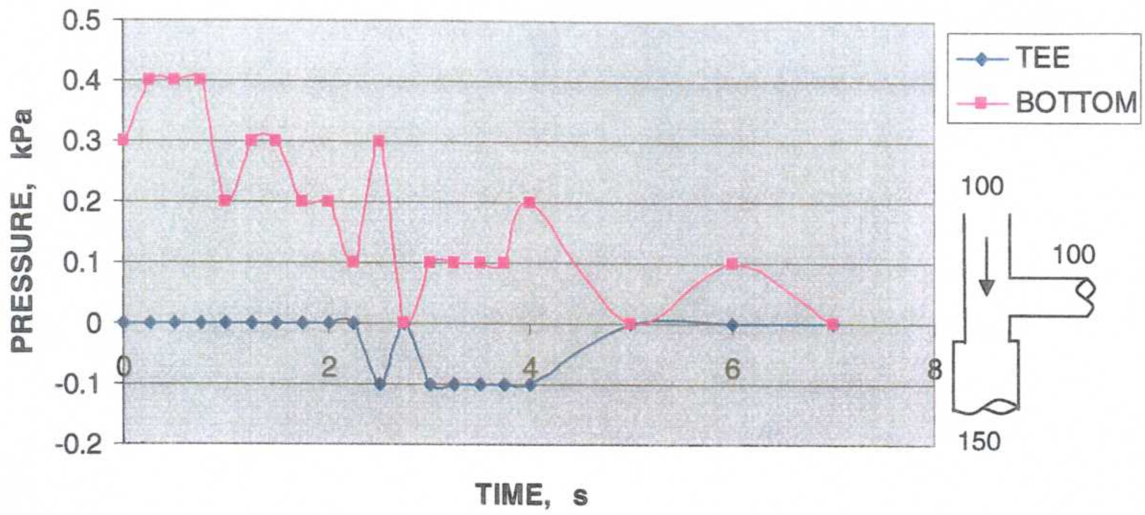
Case 2.2 Stack Pressure (vent, no downflow, branch pipe length = 3D)



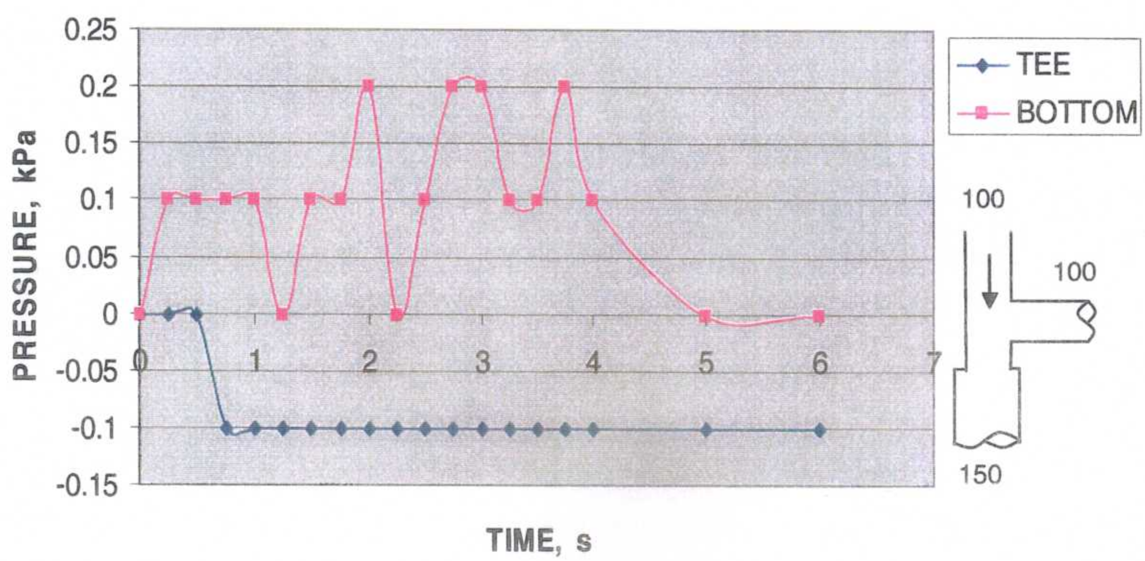
Case 2.3 Stack Pressure (vent, no downflow, branch pipe length = 38D)



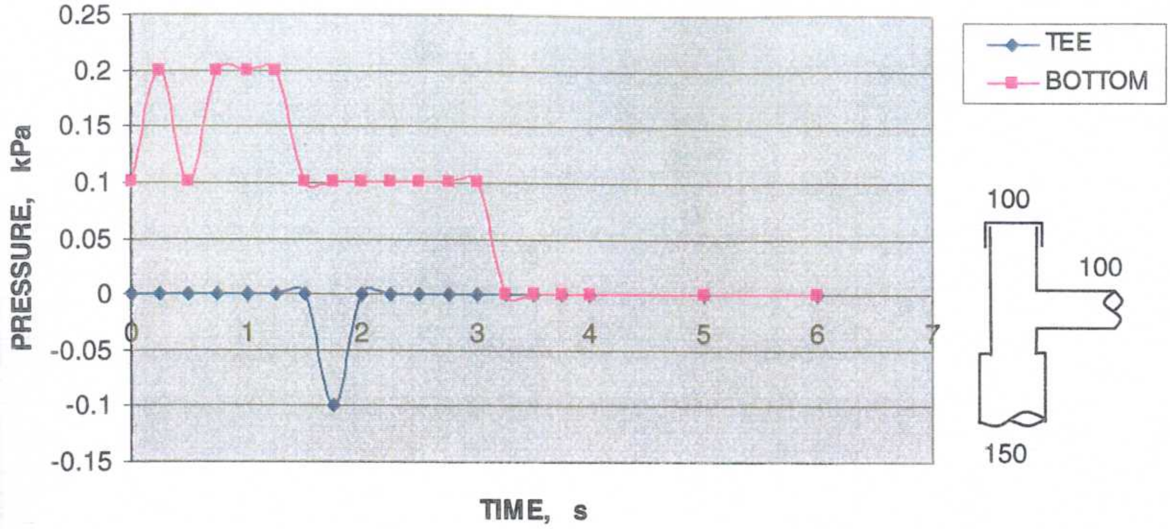
Case 2.4 Stack Pressure (vent, downflow, branch pipe length = 1D)



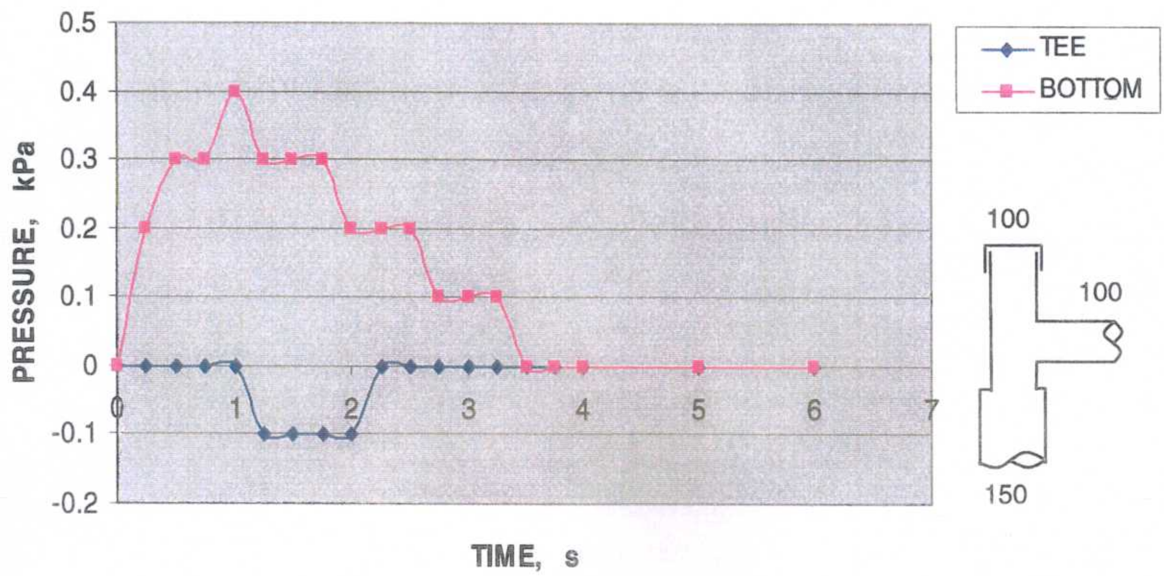
Case 2.5 Stack Pressure (vent, downflow, branch pipe length = 3D)



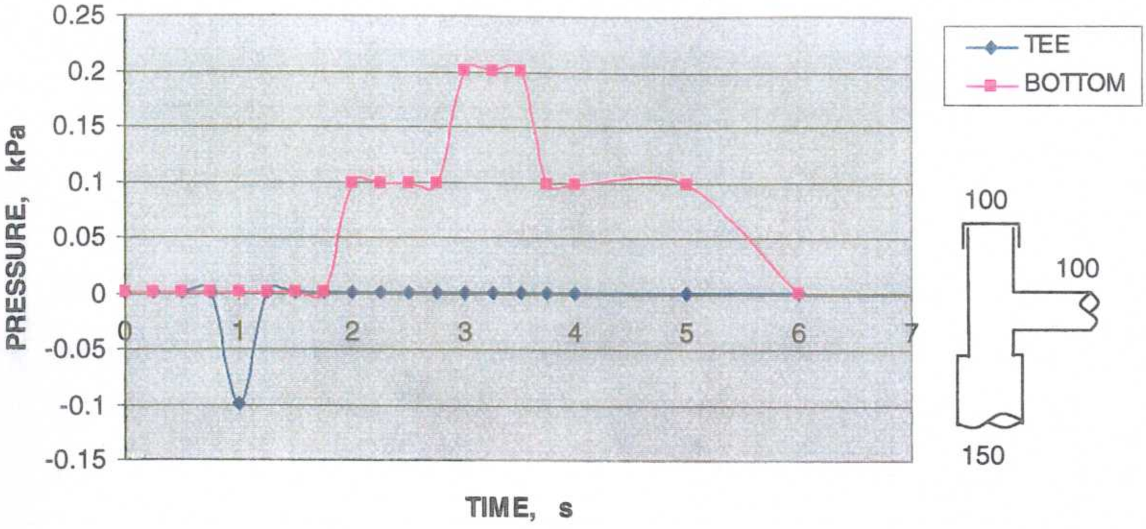
Case 2.6 Stack Pressure (vent, downflow, branch pipe length = 38D)



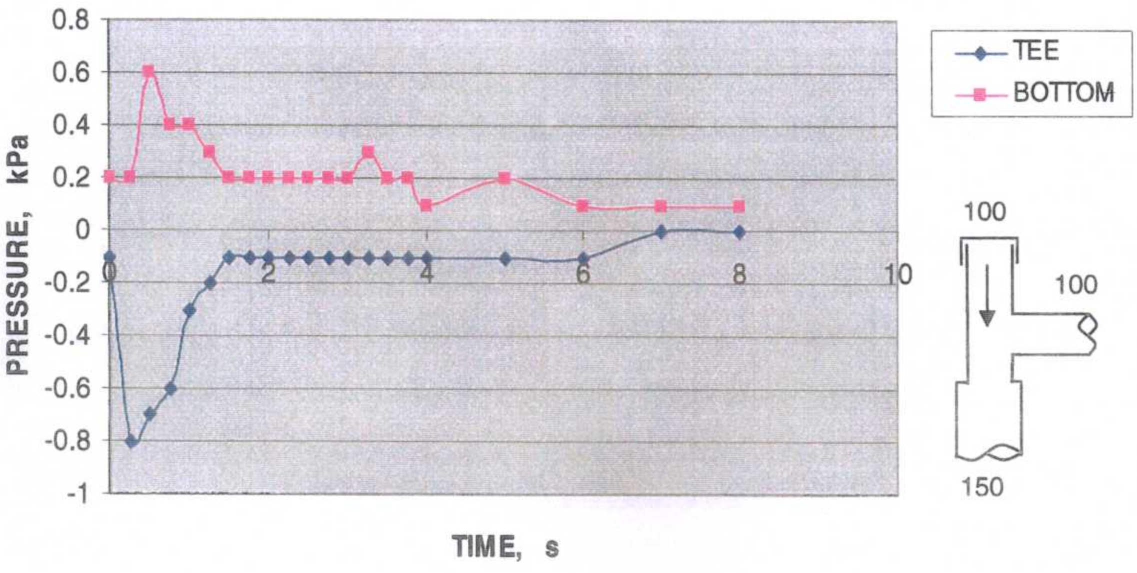
Case 2.7 Stack Pressure (unvent, no downflow, branch pipe length = 1D)



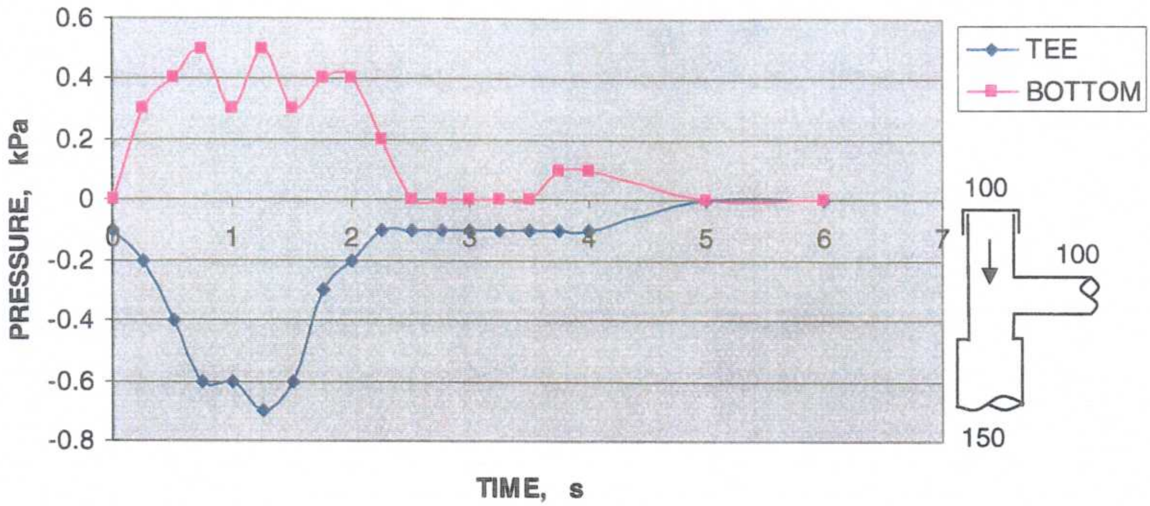
Case 2.8 Stack Pressure (unvent, no downflow, branch pipe length = 3D)



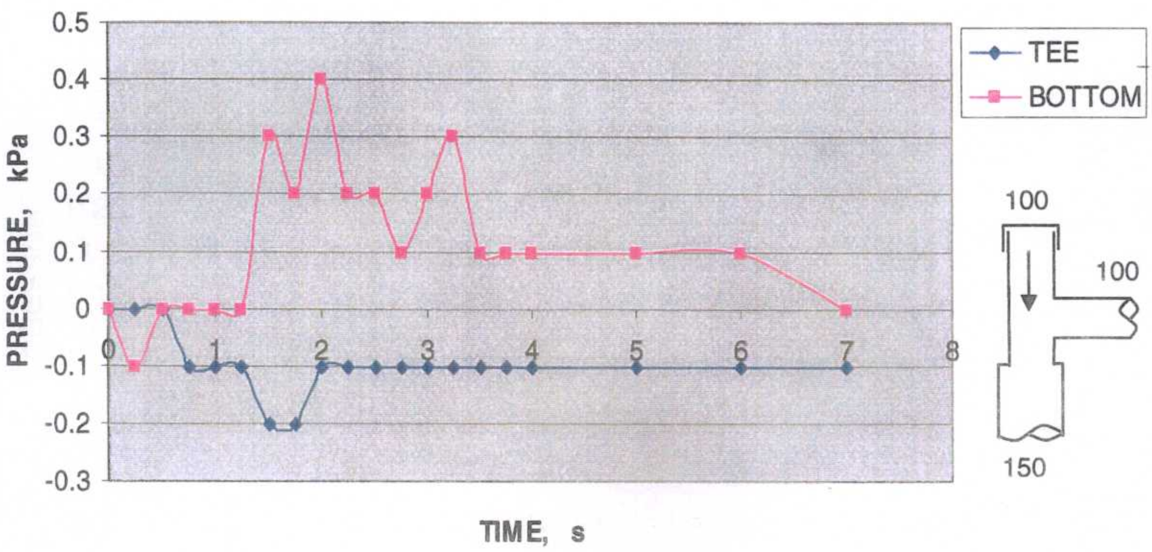
Case 2.9 Stack Pressure (unvent, no downflow, branch pipe length = 38D)



Case 2.10 Stack Pressure (unvent, downflow, branch pipe length = 1D)

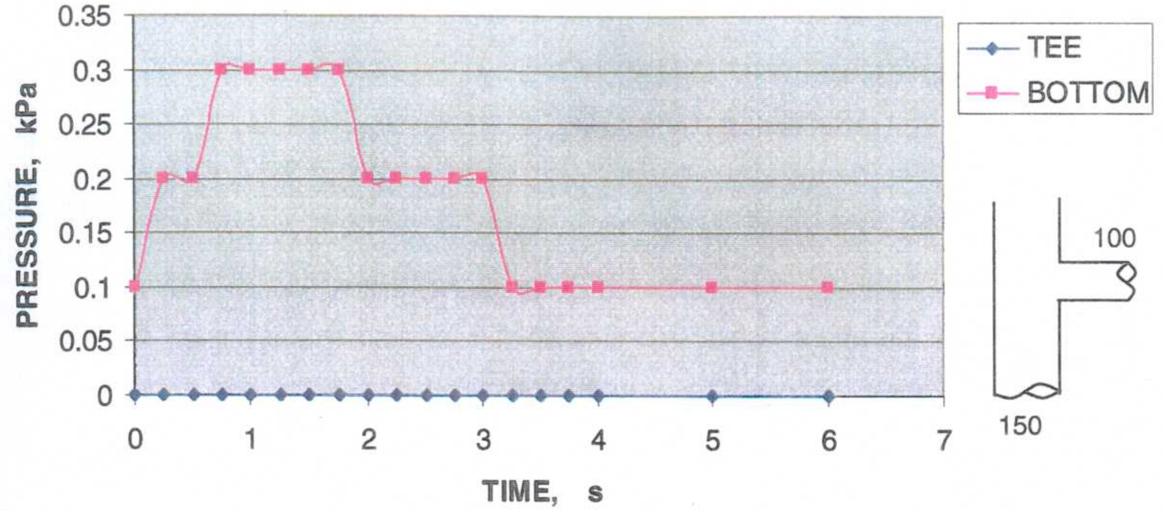


Case 2.11 Stack Pressure (unvent, downflow, branch pipe length = 3D)

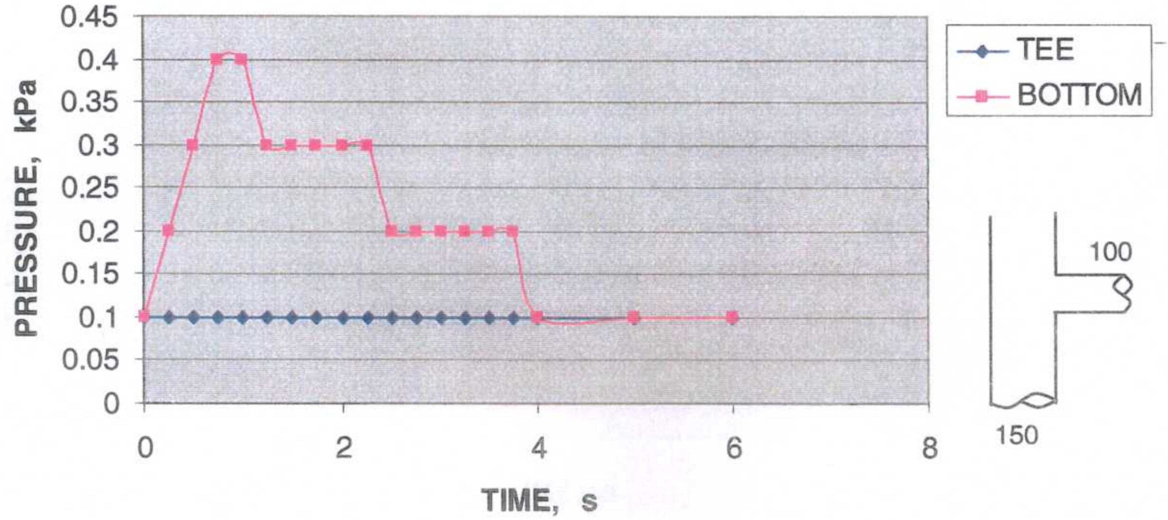


Case 2.12 Stack Pressure (unvent, downflow, branch pipe length = 38D)

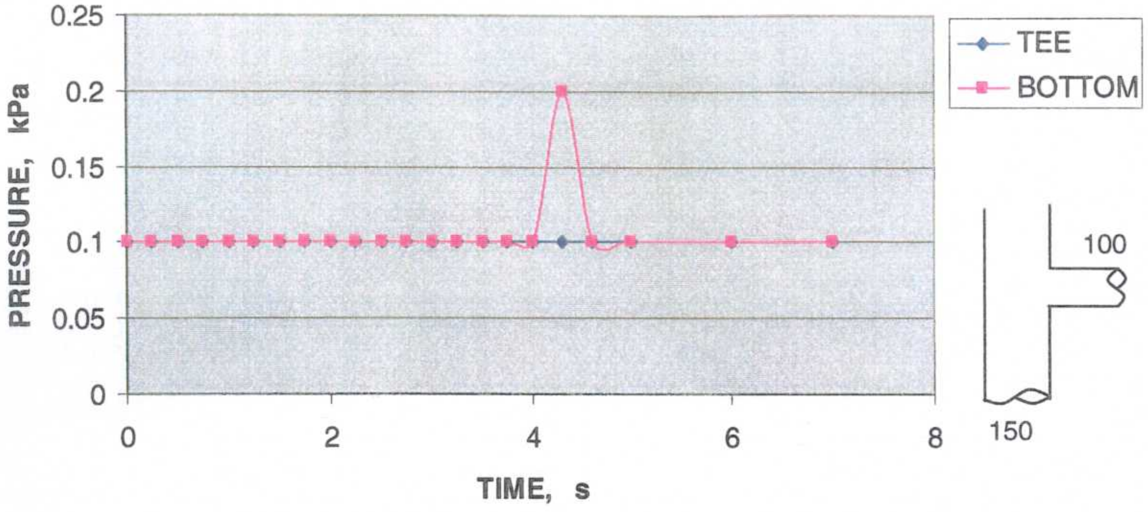
Appendix 3: Results of Test 3 (150 stack)



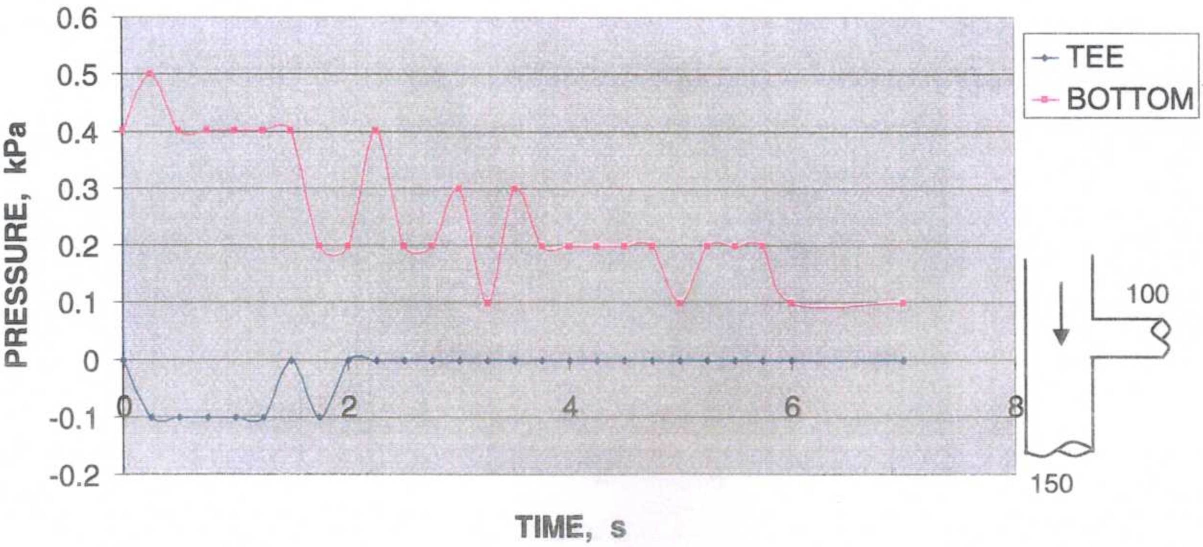
Case 3.1 Stack Pressure (vent, no downflow, branch pipe length = 1D)



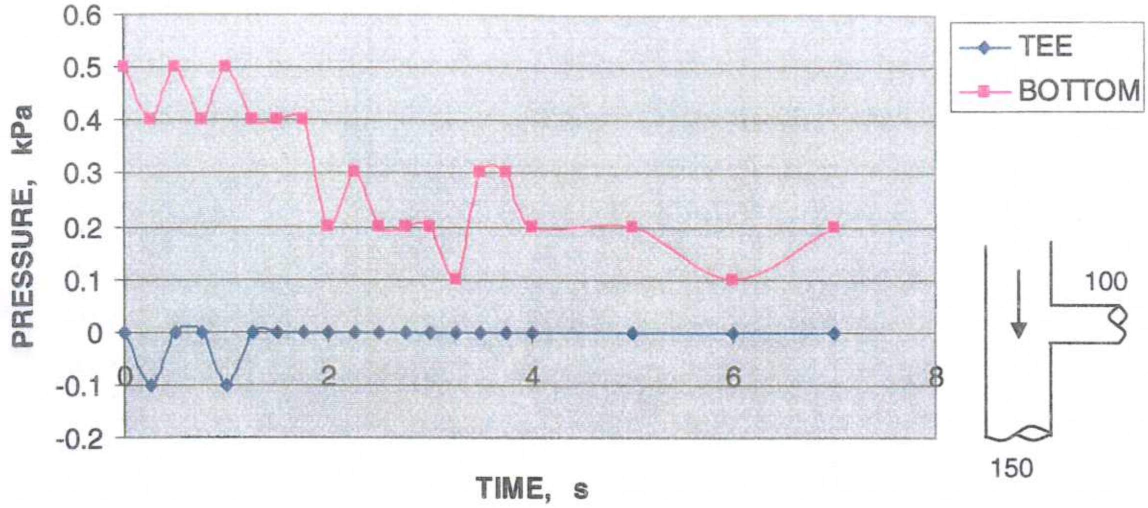
Case 3.2 Stack Pressure (vent, no downflow, branch pipe length = 3D)



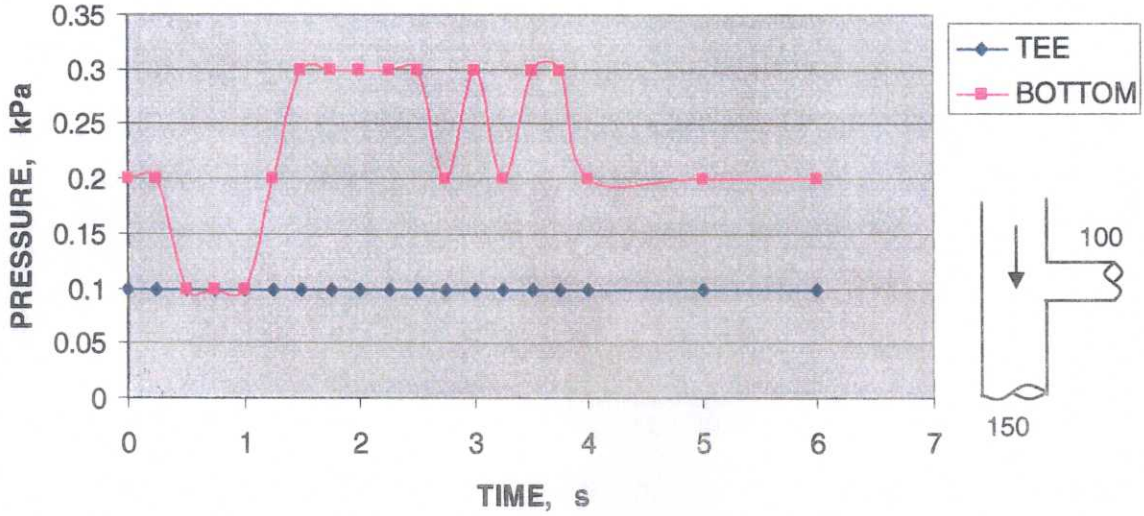
Case 3.3 Stack Pressure (vent, no downflow, branch pipe length = 38D)



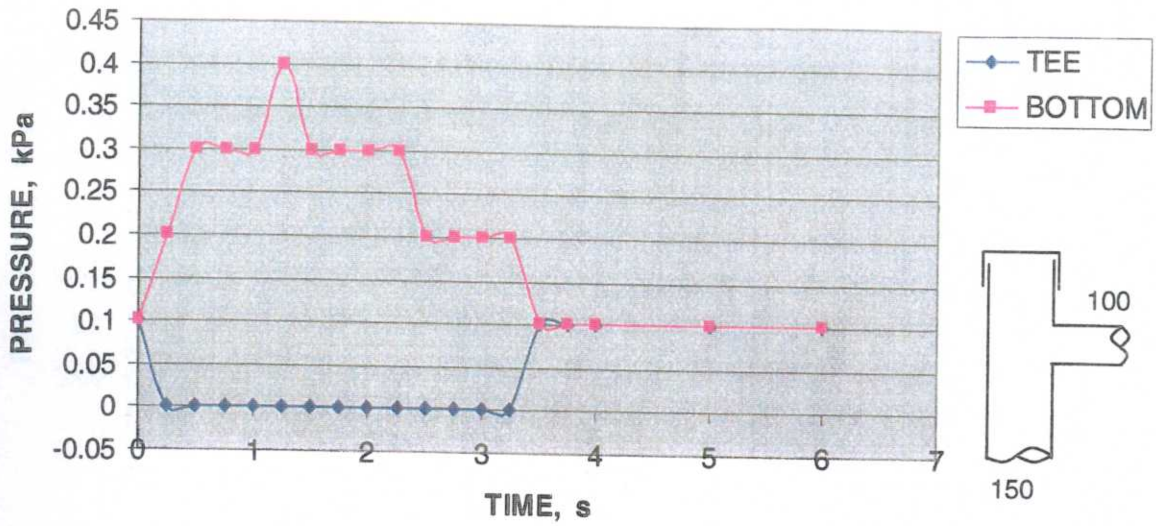
Case 3.4 Stack Pressure (vent, downflow, branch pipe length = 1D)



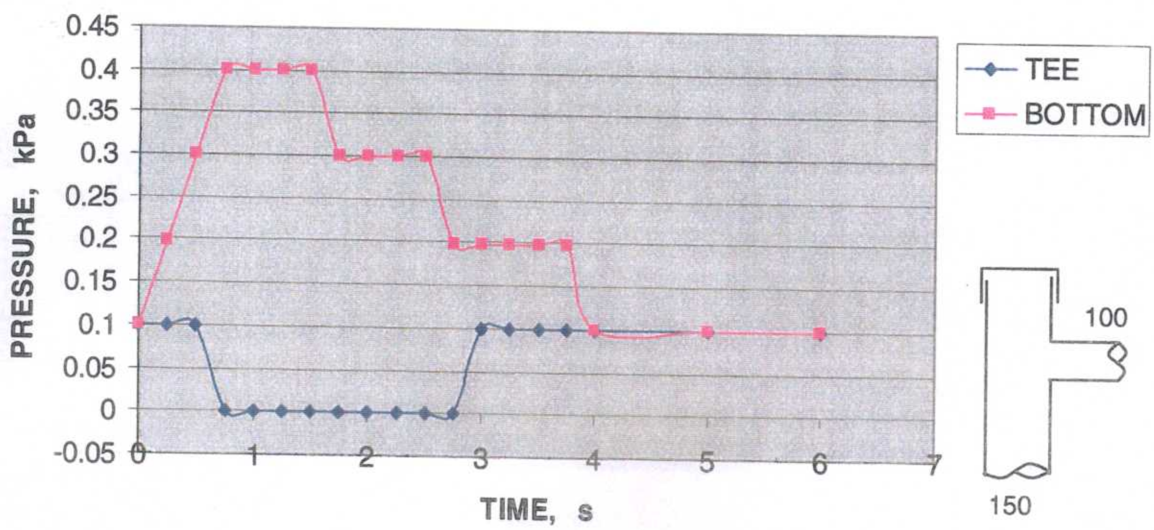
Case 3.5 Stack Pressure (vent, downflow, branch pipe length = 3D)



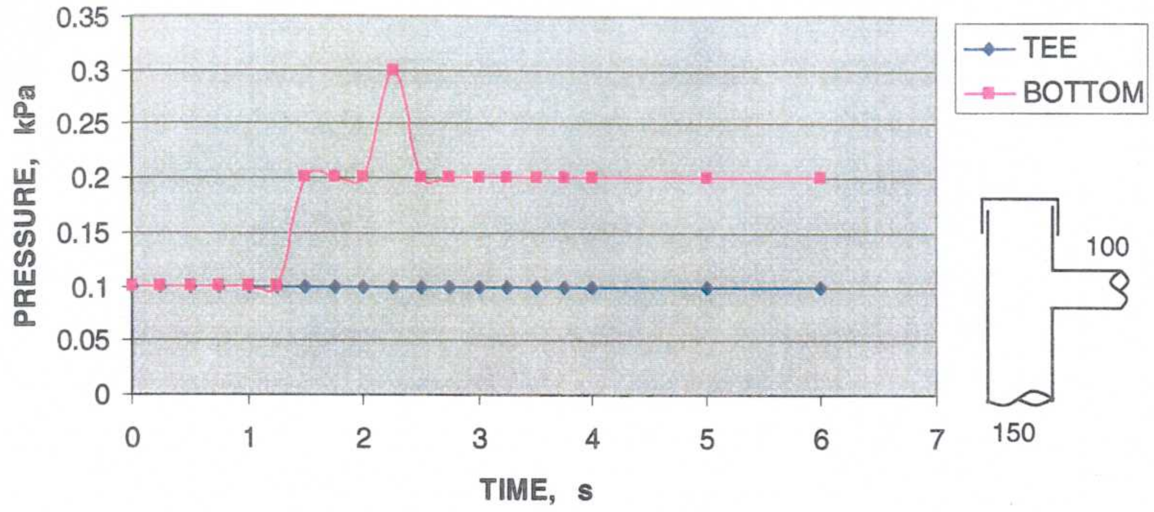
Case 3.6 Stack Pressure (vent, downflow, branch pipe length = 38D)



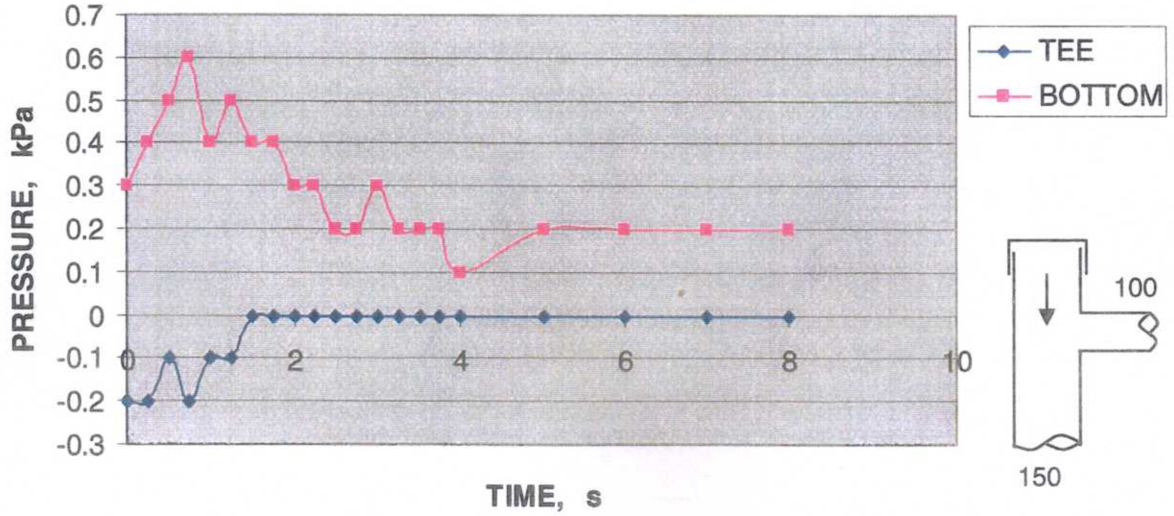
Case 3.7 Stack Pressure (unvent, no downflow, branch pipe length = 1D)



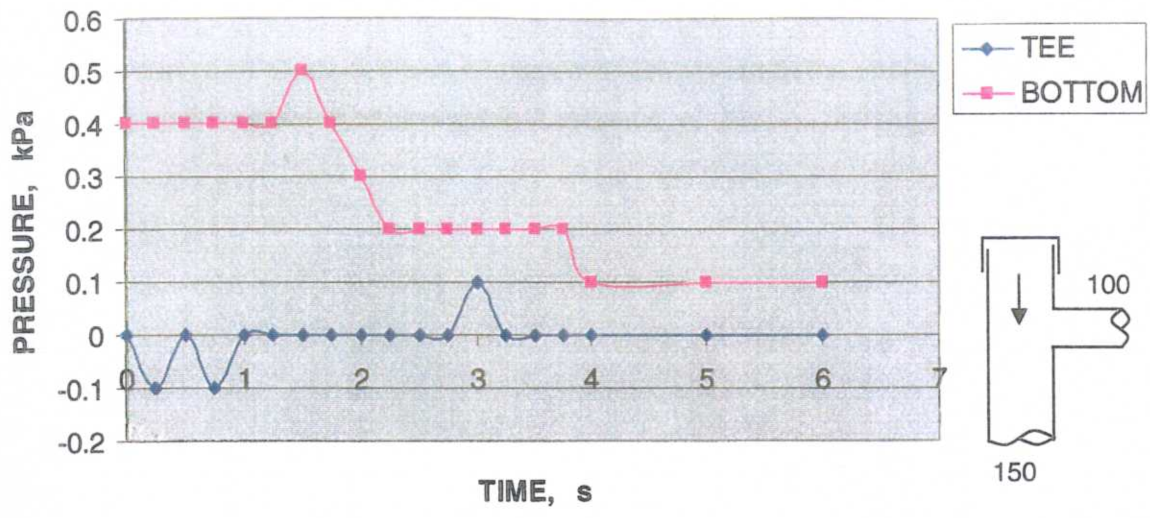
Case 3.8 Stack Pressure (unvent, no downflow, branch pipe length = 3D)



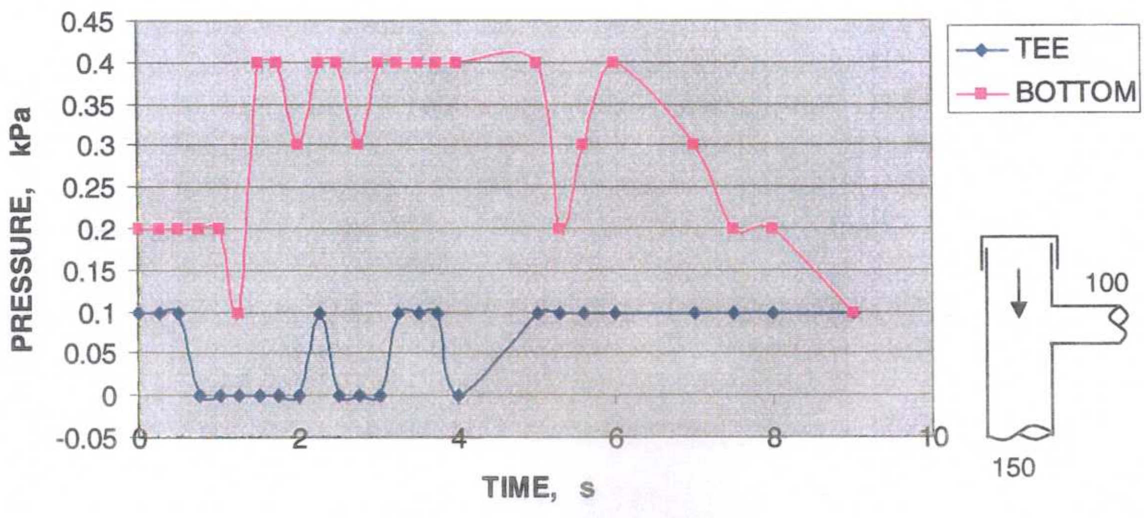
Case 3.9 Stack Pressure (unvent, no downflow, branch pipe length = 38D)



Case 3.10 Stack Pressure (unvent, downflow, branch pipe length = 1D)



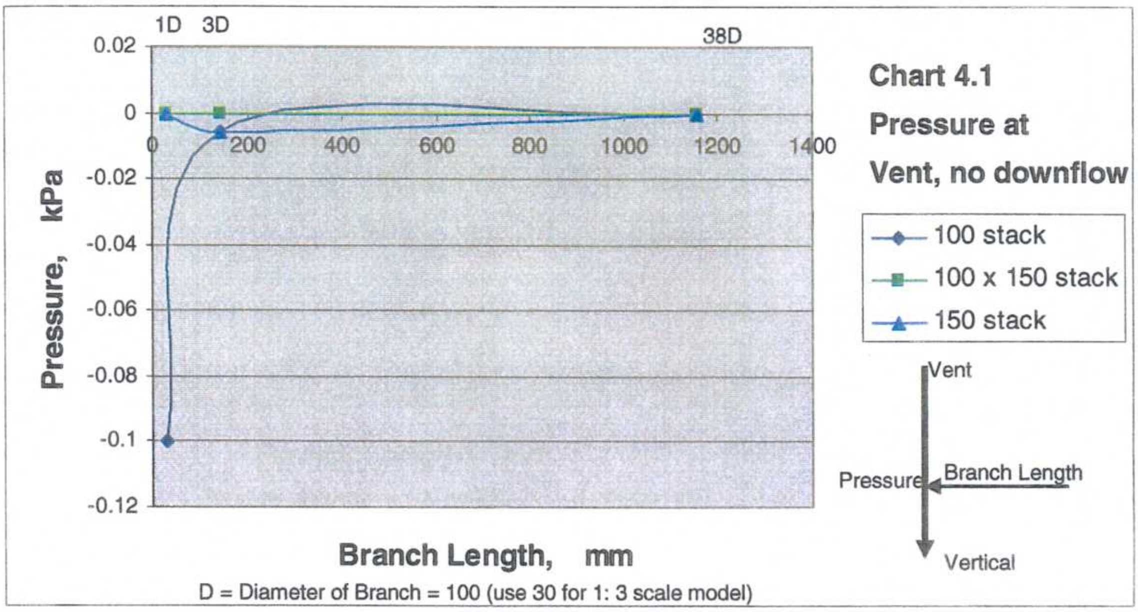
Case 3.11 Stack Pressure (unvent, downflow, branch pipe length = 3D)

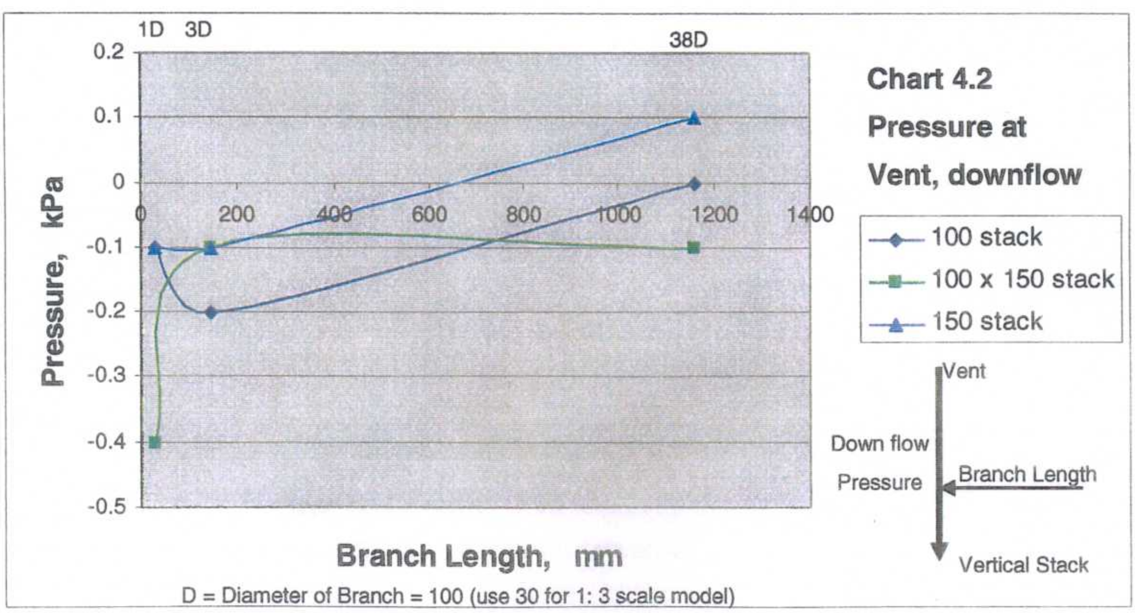


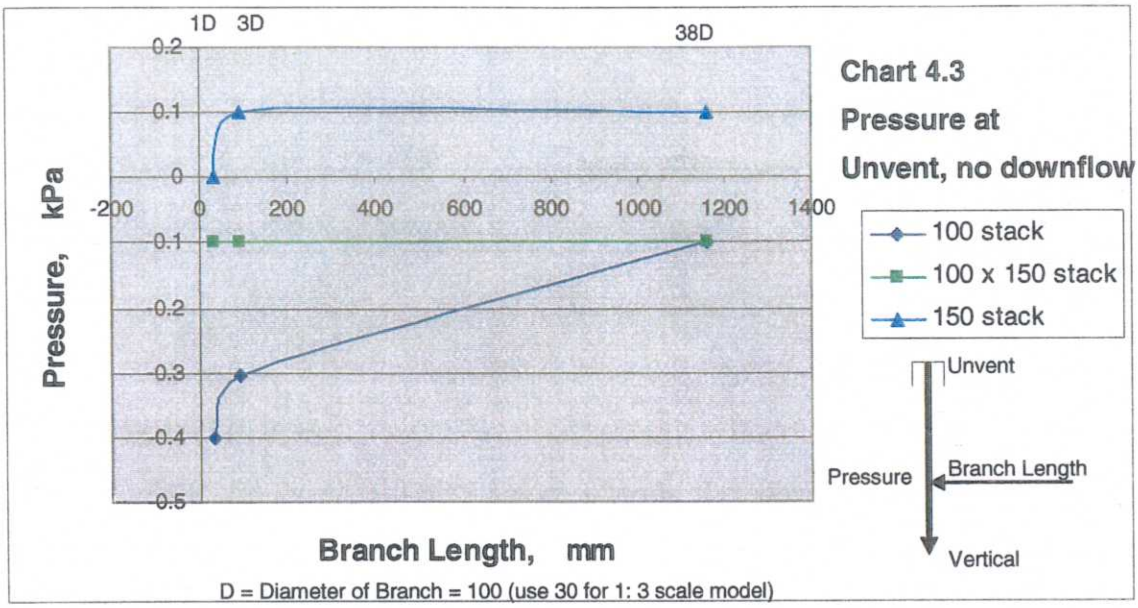
Case 3.12 Stack Pressure (unvent, downflow, branch pipe length = 38D)

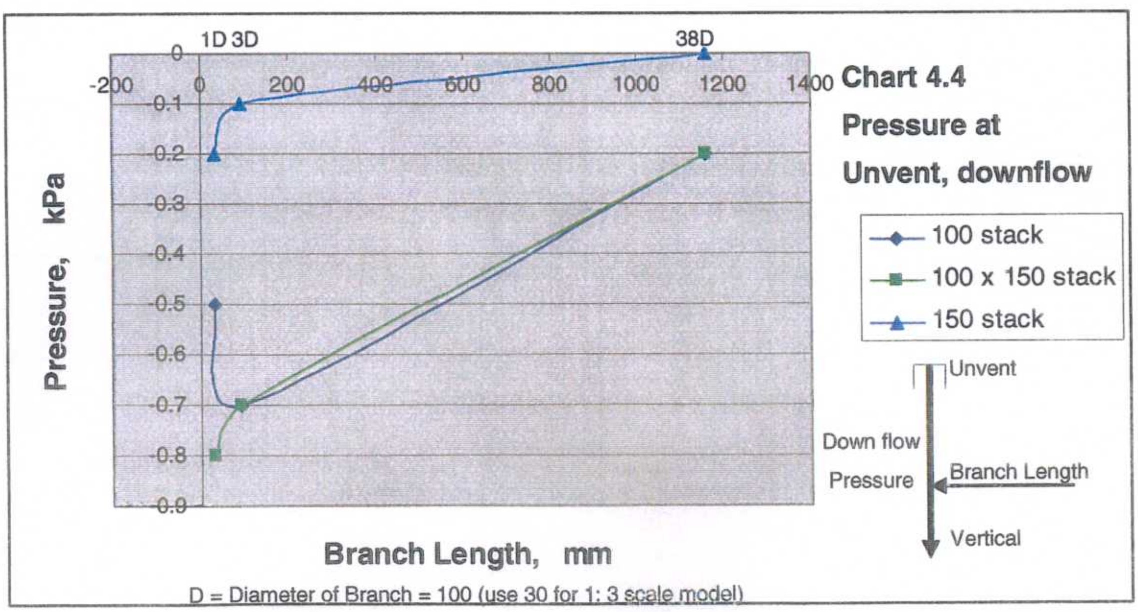
Appendix 4: Pressure Changes at Tee Junction

Data in the curves of charts 4.1 to 4.4 below are retrieved from the charts in Appendix 1, 2 & 3 by rounding up the pressure values within 2 seconds






1D 3D
38D
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-200
0
200
400
600
800
1000
1200
1400
Pressure, kPa
Branch Length, mm
D = Diameter of Branch = 100 (use 30 for 1: 3 scale model)
Chart 4.3
Pressure at
Unvent, no downflow
100 stack
100 x 150 stack
150 stack
Unvent
Pressure
Branch Length
Vertical


1D 3D
38D
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
-0.9
-200
0
200
400
600
800
1000
1200
1400
Pressure, kPa
Branch Length, mm
D = Diameter of Branch = 100 (use 30 for 1: 3 scale model)
Chart 4.4
Pressure at
Unvent, downflow
100 stack
100 x 150 stack
150 stack
Unvent
Down flow
Pressure
Branch Length
Vertical

Appendix 5: Project Team Organisation

Project Team Members

Project Leader: [redacted]

Principal Project Researcher: [redacted]

Responsibilities

[redacted]

1. To act as the project team leader in terms of planning, organizing and control.
2. To develop in conjunction with team member a framework for the investigation and to monitor the study process
3. To submit report to Client on behalf IC, PolyU

[redacted]

1. To design and set up the testing equipment – model drainage system
2. To conduct tests using the model with respect to the requirements specified by the client
3. To carry out literature review of the research topic and provide professional and expertise advice in plumbing system design & practices
4. To consolidate and summarise the readings; analyse the results and draft the findings for the final report