REFERENCES

[1] Nayak, A.K., Dubey, P., Chavan, D.N., and Vijayan , P.K. Study on the stability behaviour of two-phase natural circulation systems using a four-equation drift flux model. Nuclear Engineering and Design 237 (2007) : 386-398.

[2] Kakac, S., and Bon, B., A review of two – phase flow dynamic instabilities in tube boiling systems, International Journal of Heat and Mass Transfer 51 (2008) : 399-433.

[3] Durga Prasad, G.V., Pandey, M., and Kalra, M.S., Review of research on flow in stabilities in natural circulation boiling systems, Progress in Nuclear Energy 49 (2007) : 429-451.

[4] Nayak, A.K., and Vijayan, P.K., Flow instabilities in boiling two-phase natural circulation systems: a review, Science and Technology of Nuclear Installations (2008) : 1-15.

[5] Tadrist, T., Review on two-phase flow instabilities in narrow spaces, International Journal of Heat and Fluid Flow 28 (2007) : 54-62.

[6] Zvirin, Y., A review of natural circulation loops in pressurized water reactors and other systems, Nuclear Engineering and Design 67 (1981) : 203-225.

[7] Boure, J.A., Bergles, A.E., and Tong, L.S., Review of two-phase flow instability, Nuclear Engineering and Design 25 (1973) : 165-192.

[8] Aritomi, M., Chiang, J. H., and Mori, M., Geysering in parallel boiling channels, Nuclear Engineering and Design 141 (1993) : 111-121.

[9] Chiang, J.H., Aritomi, M., Inoue, R., and Mori, M., Thermo-hydraulics during start-up in natural circulation boiling water reactors, Nuclear Engineering and Design 146 (1994) : 241-251.

[10] Kuran, S., et al., Startup transient simulation for natural circulation boiling water reactors in PUMA facility, Nuclear Engineering and Design 236 (2006) : 2365-2375.

[11] Furuya, M., Inada, F., and van der Hagen, T.H.J.J., Flashing-induced density wave oscillations in a natural circulation BWR – mechanism of instability and stability map, Nuclear Engineering and Design 235 (2005) : 1557-1569.

[12] Paniagua, J., Rohatgi, U.S., and Prasad, V., Modeling of thermal hydraulic instabilities in single heated channel loop during startup transients, Nuclear Engineering and Design 193 (1999) : 207-226.

[13] Chaiwat Muncharoen, The effect of flow loop conditions on stabilities of two – phase natural circulation caused by boiling, Doctoral dissertation, Department of Nuclear Technology, Faculty of Engineering, Chulalongkorn University, 2002.

[14] Nayak, A.K., et al., A numerical study of boiling flow instability of a reactor thermosyphon system, Applied Thermal Engineering 26 (2006) 644-653.

[15] Rao, N.M., Chandra Sekhar, Ch., Maiti, B., and Das, P.K., Steady-state performance of a two-phase natural circulation loop, International Communications in Heat and Mass Transfer 33 (2006) : 1042-1052.

[16] Wu, C.Y., Wang, S.B., and Pan. C., Chaotic oscillations in a low pressure two-phase natural circulation loop under low power and high inlet subcooling conditions, Nuclear Engineering and Design 162 (1996) : 223-232.

[17] Situ, R., et al., Flow structure of subcooled boiling flow in an internally heated annulus, International Journal of Heat and Mass Transfer 47 (2004) : 5351-5364.

[18] Khodabandeh, R., Furberg, R., Instability, heat transfer and flow regime in a two-phase flow thermosyphon loop at different diameter evaporator channel, Applied Thermal Engineering 30 (2010) : 1107-1114.

[19] Yun, G., Cheng, G., Heyi, Z., The application of Fast Fourier Transform (FFT) method in the twin-channel system instability under ocean conditions, Annals of Nuclear Energy 37 (2010) : 1048-1055.

[20] Kosar, A., Özdemir, M.R., Keskinoz M., Pressure drop across micro-pin heat sinks under unstable boiling conditions. International Journal of Thermal Sciences 49 (2010) : 1253-1263.

[21] Thome, J.R., Engineering data book III, Wolverine Tube, 2006.

[22] Baehr, H.D., and Stephan, K., Heat and Mass Transfer, 2nd Berlin : Springer, 2006.

[23] Ambrosini, W., Lecture notes for the course on single and two-phase thermal-Hydraulics, University of Pisa, Italy.

[24] Young, M.F., The TEXAS code for fuel-coolant interaction analysis, Proc. ANS/ENS LMFBR Safety Topical Mtg., Lyon-Ecully, France, 1982.

[25] Chu C.C., et al., A dynamic model for droplet fragmentation, Transaction of American Nuclear Society 47 (1984).

[26] Tang, J., Modeling of the complete process of one-dimensional vapor explosions, Doctoral dissertation, University of Wisconsin, 1993.

[27] Murphy, J., A hydrogen generation model for TEXAS, Master's Thesis, University of Wisconsin, 1992.

[28] Chu, C.C., One-dimensional transient fluid model for fuel-coolant interaction analysis, Doctoral dissertation, University of Wisconsin, 1986.

Appendices

Appendix A.1 Temperature profiles for the NCL#2

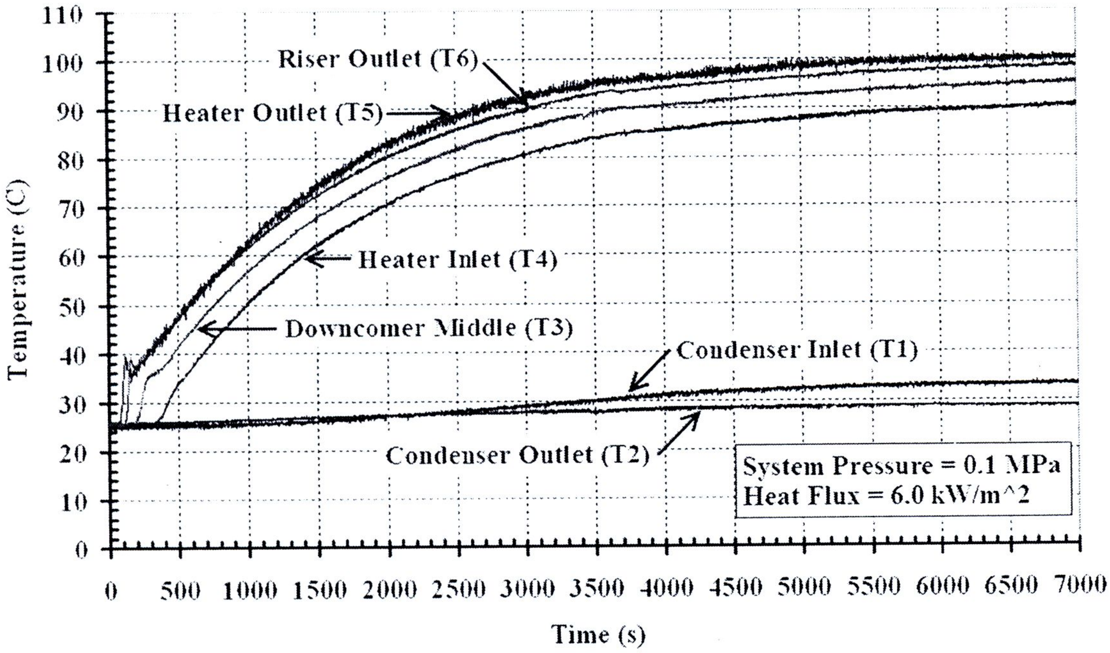

Fig. A1.1 Temperature profiles at 6.0 kW/m^2 heat flux

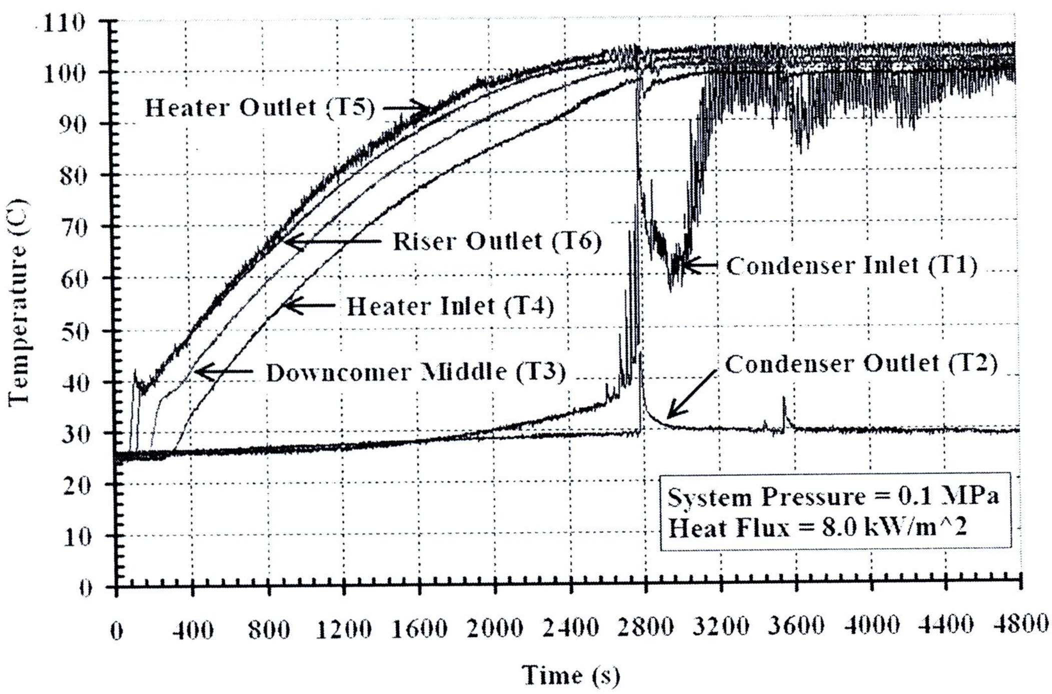

Fig. A1.2 Temperature profiles at 8.0 kW/m^2 heat flux

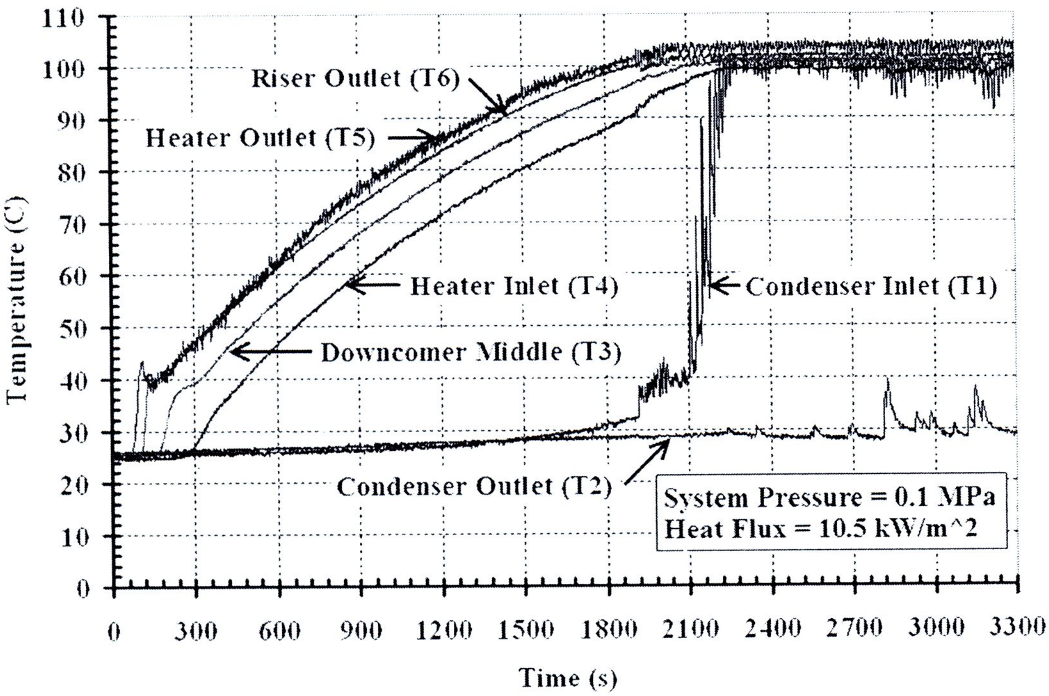

Fig. A1.3 Temperature profiles at 10.5 kW/m^2 heat flux

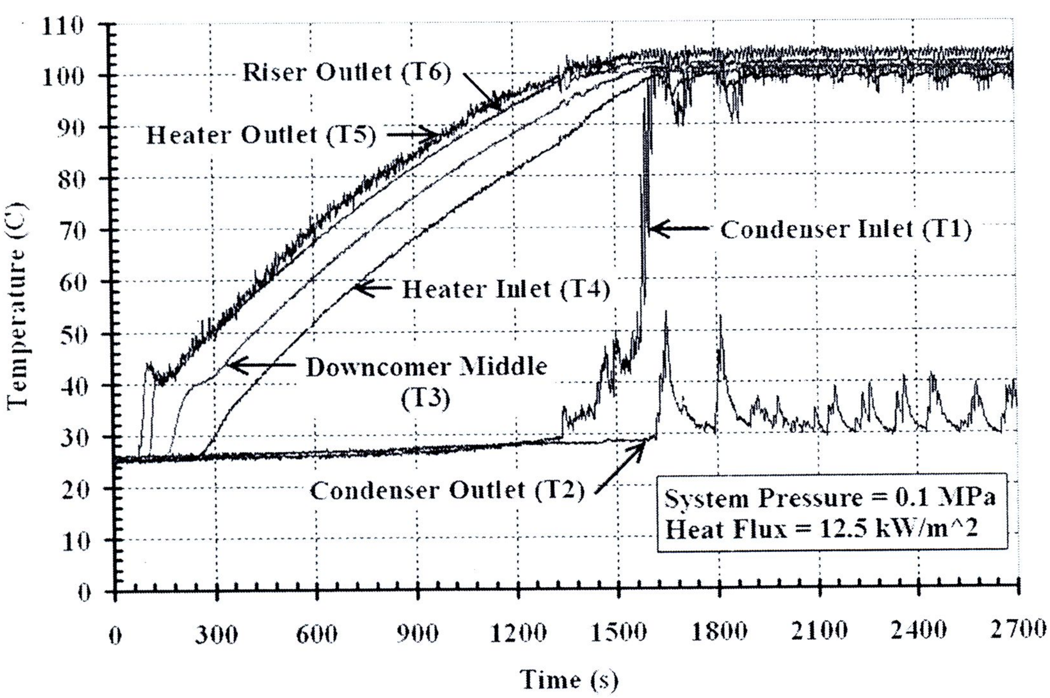

Fig. A1.4 Temperature profiles at 12.5 kW/m^2 heat flux

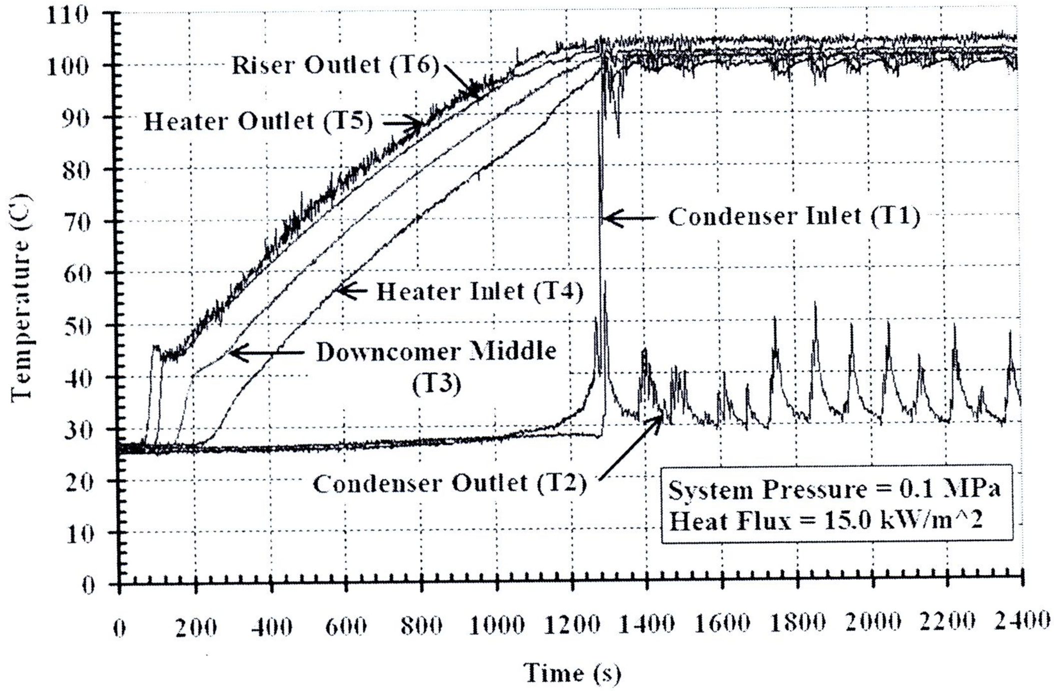

Fig. A1.5 Temperature profiles at 15.0 kW/m^2 heat flux

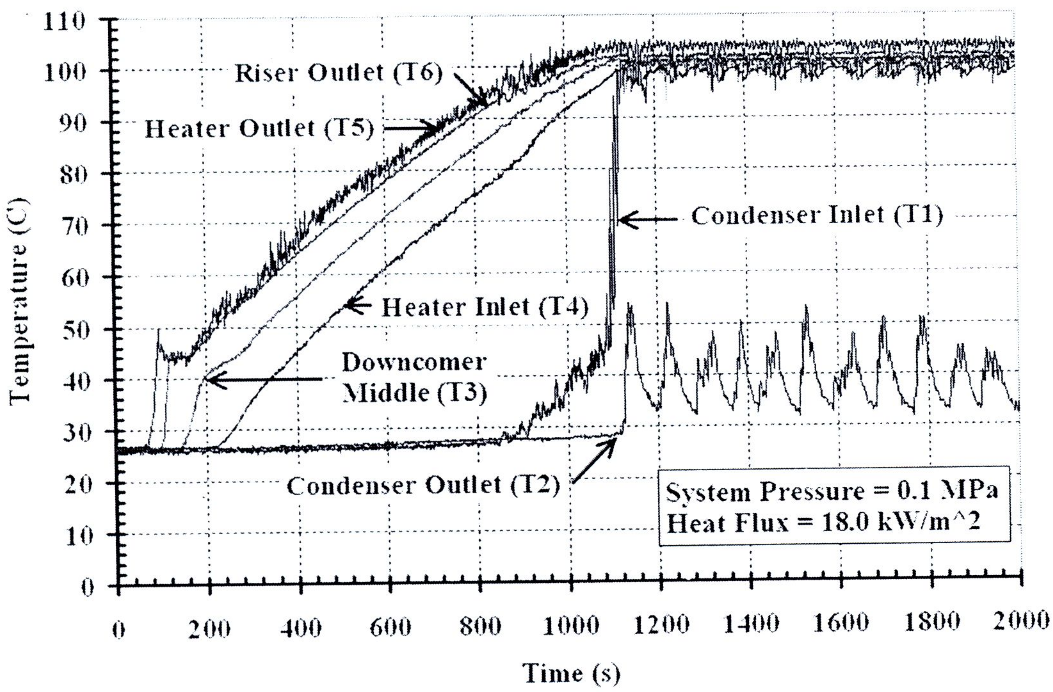

Fig. A1.6 Temperature profiles at 18.0 kW/m^2 heat flux

Appendix A.2 Differential pressure across the heater for the NCL#2

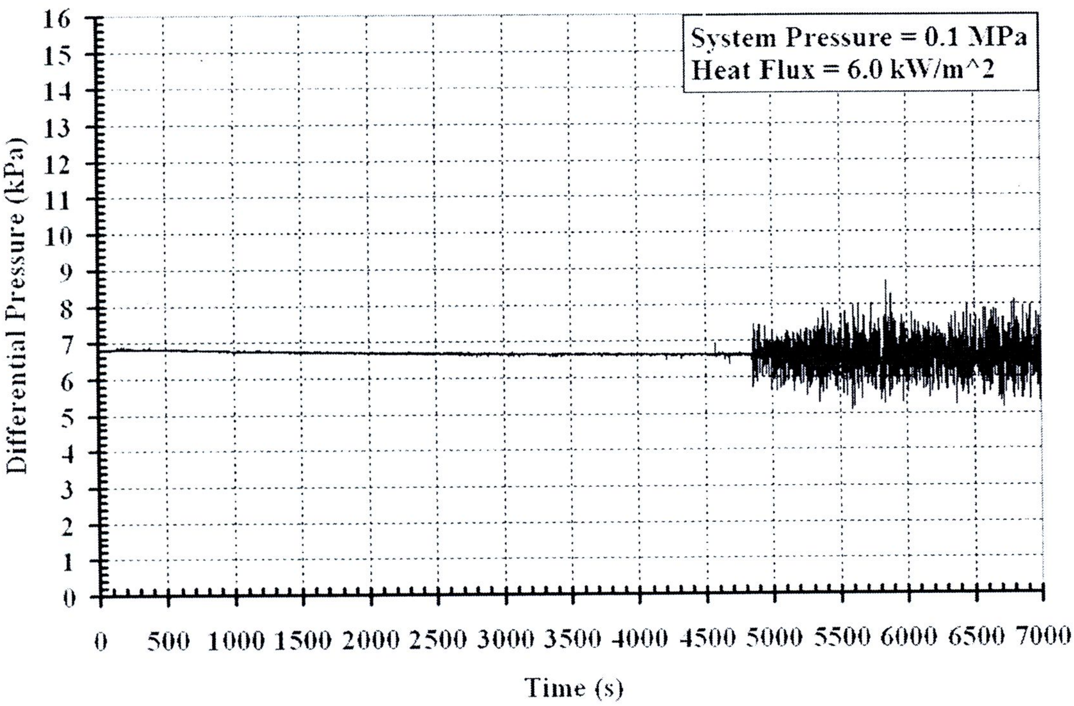

Fig. A2.1 Differential pressure across the heater at 6.0 kW/m^2 heat flux

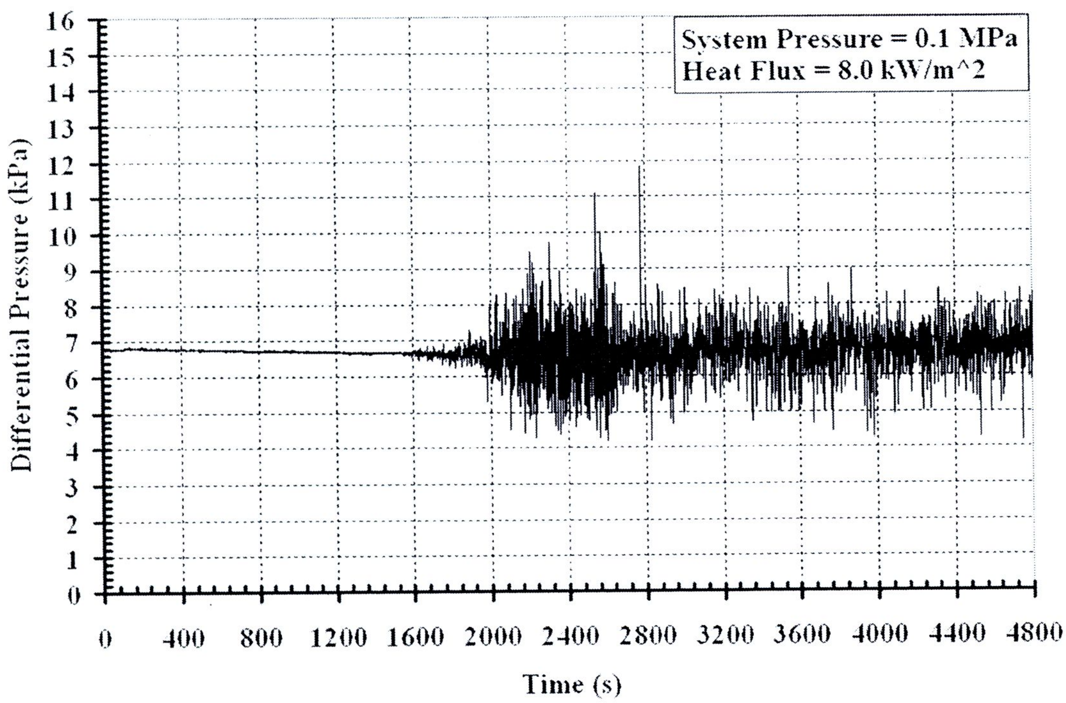

Fig. A2.2 Differential pressure across the heater at 8.0 kW/m^2 heat flux

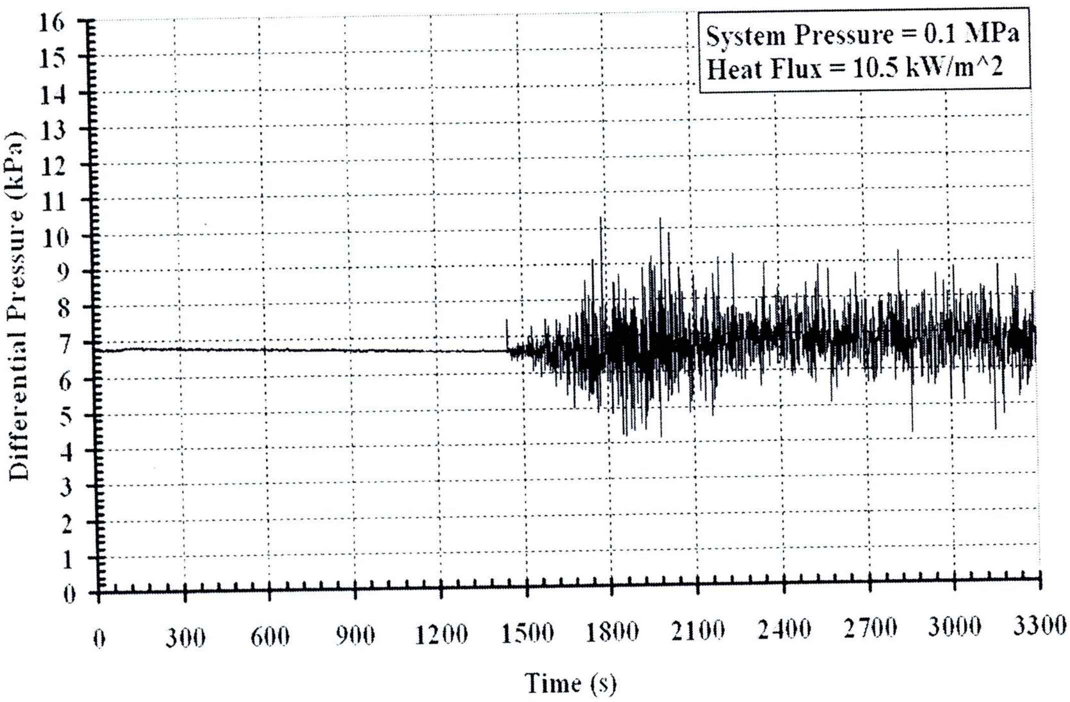

Fig. A2.3 Differential pressure across the heater at 10.5 kW/m^2 heat flux

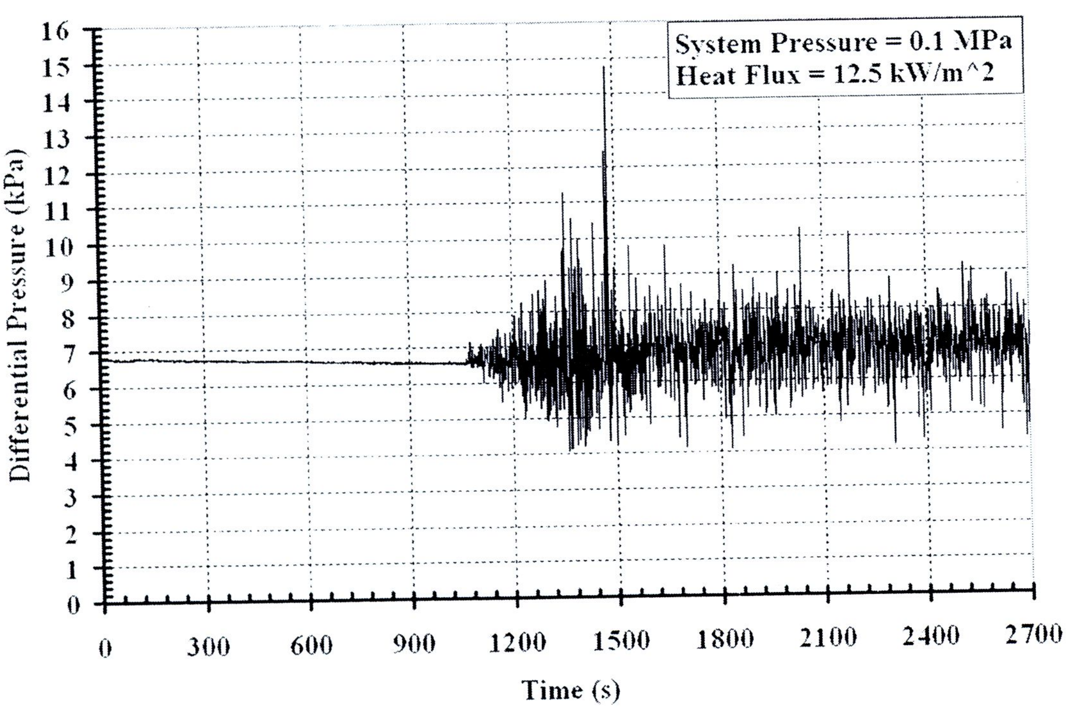

Fig. A2.4 Differential pressure across the heater at 12.5 kW/m^2 heat flux

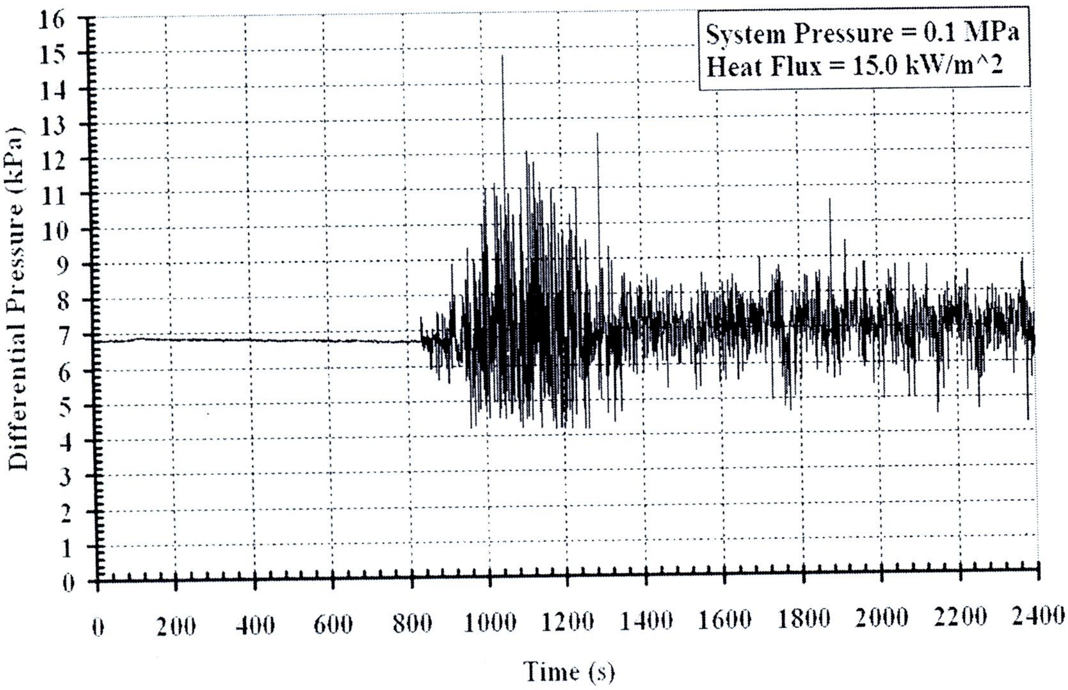

Fig. A2.5 Differential pressure across the heater at 15.0 kW/m^2 heat flux

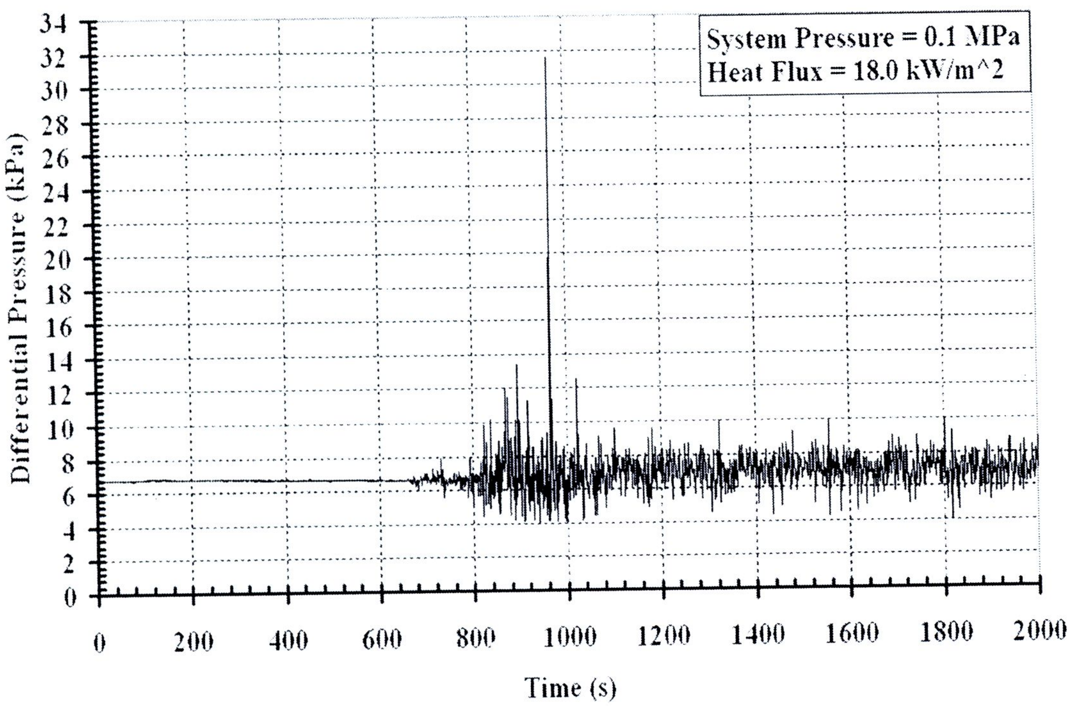

Fig. A2.6 Differential pressure across the heater at 18.0 kW/m^2 heat flux

Appendix B.1 MATLAB code for FFT

```
load Pressure.txt
t = Pressure(:,1)';            % Time (s)
temp = Pressure(:,2)';  % Heat flux = 8.0 kW/m^2
%temp = Pressure(:,3)';  % Heat flux = 10.5 kW/m^2
%temp = Pressure(:,4)';  % Heat flux = 12.5 kW/m^2
%temp = Pressure(:,5)';  % Heat flux = 15.0 kW/m^2
%temp = Pressure(:,6)';  % Heat flux = 18.0 kW/m^2
n = length(temp);       %Number of samples
c = polyfit(t,temp,1);
trend = polyval(c,t);
subplot(2,2,1);
plot(t,[temp;trend],'r-',t,temp,'k-','linewidth',2)
grid on;                %Turn on grid lines for this plot
set(gca,'XLim',[400 800]);
set(gca,'XTickLabel',{400:100:800},...
            'FontName','times',...
            'FontSize',14);
set(get(gca,'XLabel'),'String','Time (s)',...
            'FontName','times',...
            'FontSize',14);
set(get(gca,'YLabel'),'String','Differential Pressure (kPa)',...
            'FontName','times',...
            'FontSize',14);
set(get(gca,'Title'),'String','Differential pressure across the heater with linear trend',...
            'FontName','times',...
            'FontSize',14);
y = temp - trend;
Y = fft(y);             %Finite Fourier Transform
Fs = 1;                 %Sample rate
```

```
f = (1:n/2)*Fs/n;        %Nyquist frequency (n/2)*(Fs/n) = Fs/2
power = abs(Y(1:floor(n/2))).^2;
subplot(2,2,2);
plot(f,power,'k-','linewidth',2)
grid on;
set(gca,'XLim',[0 0.5]);
set(gca,'XTickLabel',{0:0.1:0.5},...
            'FontName','times',...
            'FontSize',14);
set(get(gca,'XLabel'),'String','Frequency (Hz)',...
            'FontName','times',...
            'FontSize',14);
set(get(gca,'YLabel'),'String','Power',...
            'FontName','times',...
            'FontSize',14);
set(get(gca,'Title'),'String','Periodogram',...
            'FontName','times',...
            'FontSize',14);
text(0.25,4.2e3,'{Heat Flux = 8.0 kW/m}^{2}',...
            'VerticalAlignment','bottom',...
                  'HorizontalAlignment','left',...
                  'FontSize',14,...
            'EdgeColor','black',...
            'BackgroundColor',[1 1 1]);
period=1./f;
subplot(2,2,3);
plot(period,power,'k-','linewidth',2)
%axis([0 50 0 5e3]);
grid on;
set(gca,'XLim',[0 50]);
set(gca,'XTickLabel',{0:10:50},...
```

```
                'FontName','times',...
                'FontSize',14);
set(get(gca,'XLabel'),'String','Period (s)',...
                'FontName','times',...
                'FontSize',14);
set(get(gca,'YLabel'),'String','Power',...
                'FontName','times',...
                'FontSize',14);
set(get(gca,'Title'),'String','Short Oscillation Period',...
                'FontName','times',...
                'FontSize',14);
subplot(2,2,4);
plot(period,power,'k-','linewidth',2)
axis([50 300 0 5e3]);
grid on;
set(gca,'XLim',[50 300]);
set(gca,'XTickLabel',{50:50:300},...
                'FontName','times',...
                'FontSize',14);
set(get(gca,'XLabel'),'String','Period (s)',...
                'FontName','times',...
                'FontSize',14);
set(get(gca,'YLabel'),'String','Power',...
                'FontName','times',...
                'FontSize',14);
set(get(gca,'Title'),'String','Long Oscillation Period',...
                'FontName','times',...
                'FontSize',14);
```

Appendix B.2 FFT profiles of temperature at the heater outlet for the NCL#2

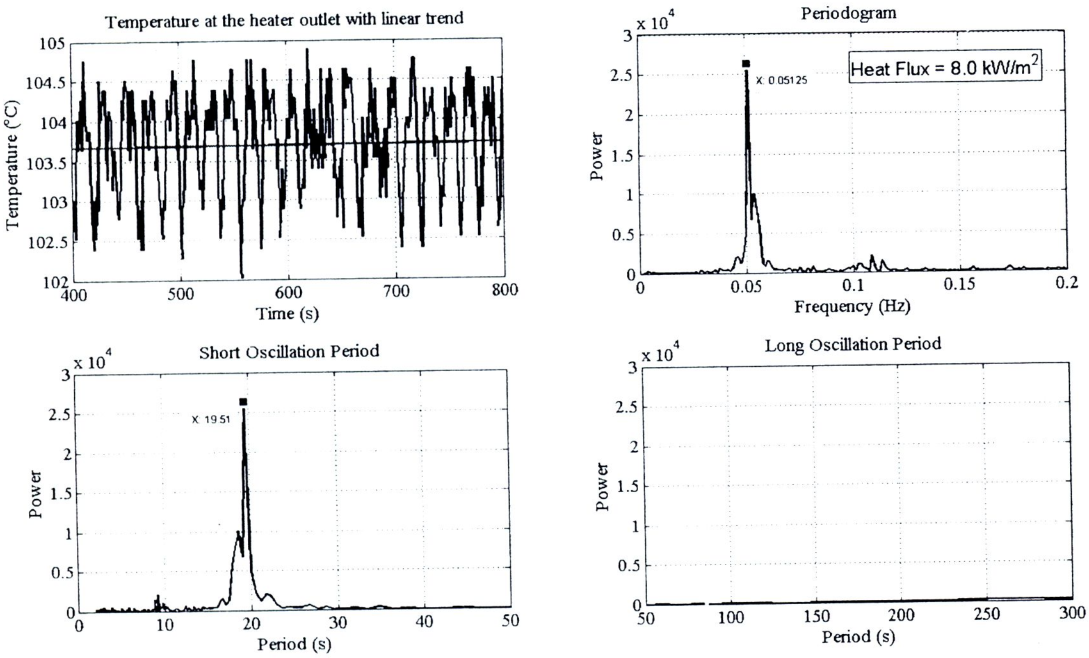

Fig. B2.1 FFT profile of temperature at the heater outlet at 8.0 kW/m^2 heat flux

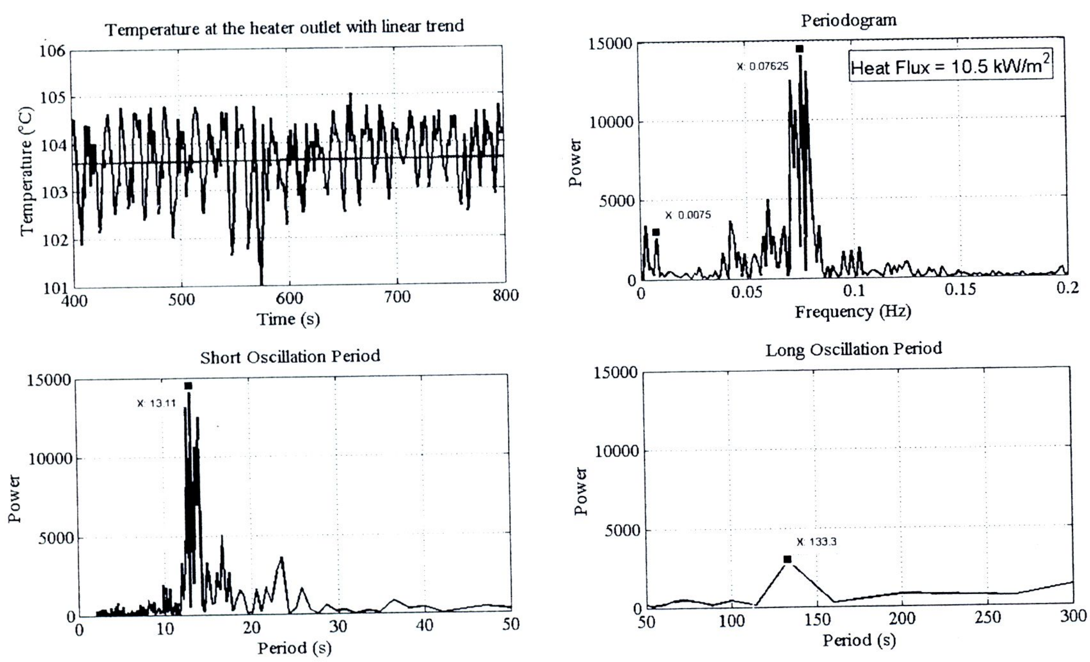

Fig. B2.2 FFT profile of temperature at the heater outlet at 10.5 kW/m^2 heat flux

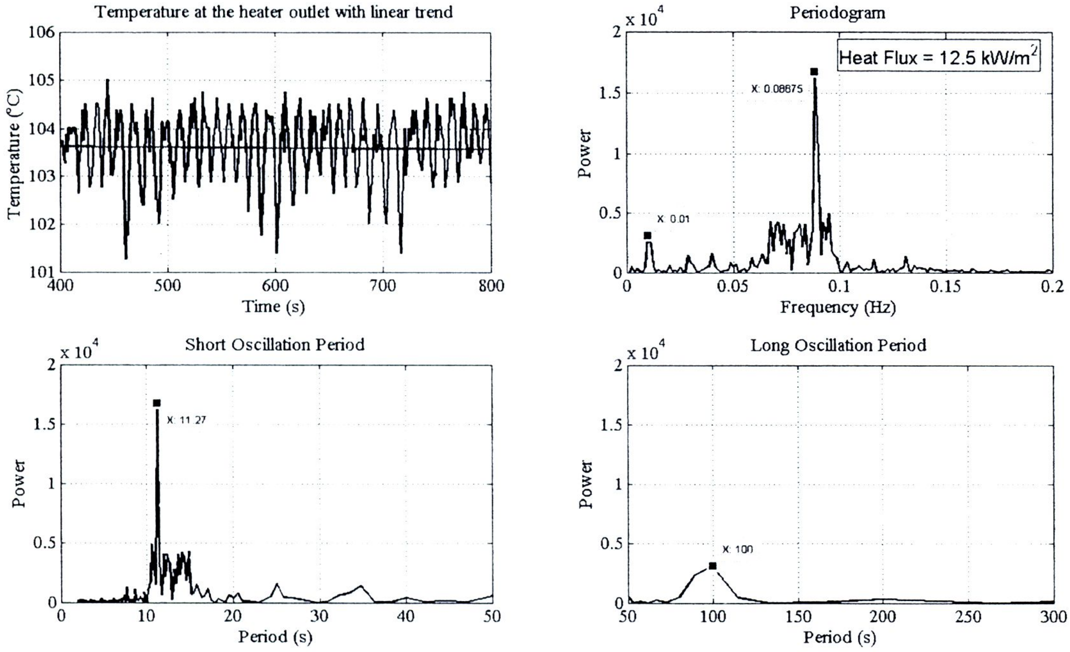

Fig. B2.3 FFT profile of temperature at the heater outlet at 12.5 kW/m^2 heat flux

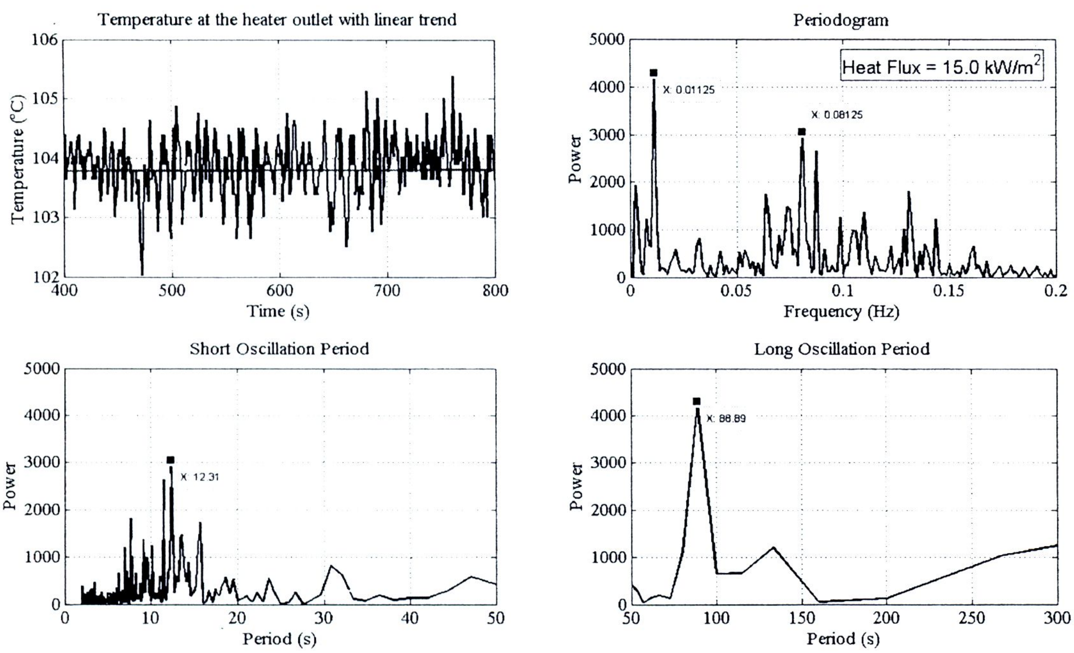

Fig. B2.4 FFT profile of temperature at the heater outlet at 15.0 kW/m^2 heat flux

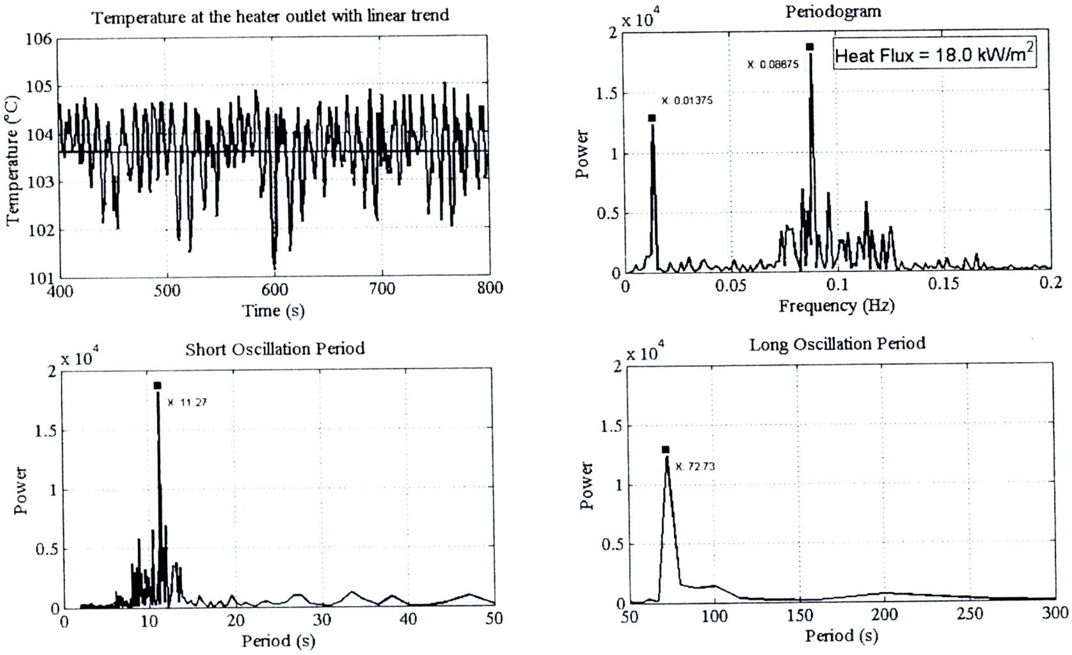

Fig. B2.5 FFT profile of temperature at the heater outlet at 18.0 kW/m^2 heat flux

Appendix B.3 FFT profiles of temperature at the condenser outlet for the NCL#2

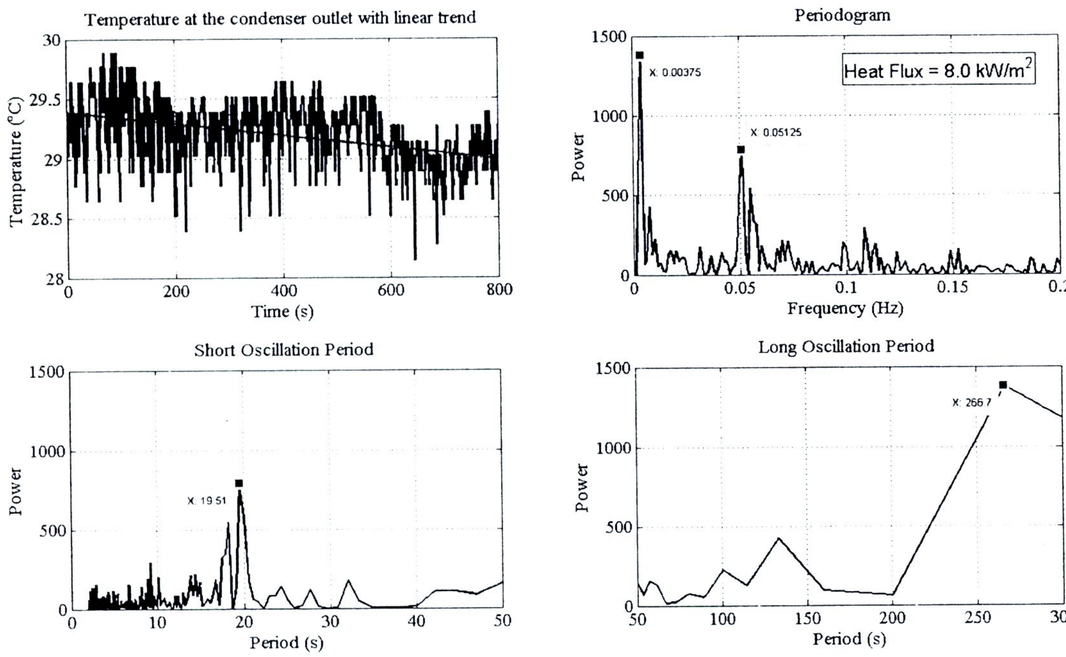

Fig. B3.1 FFT profile of temperature at the condenser outlet at 8.0 kW/m^2 heat flux

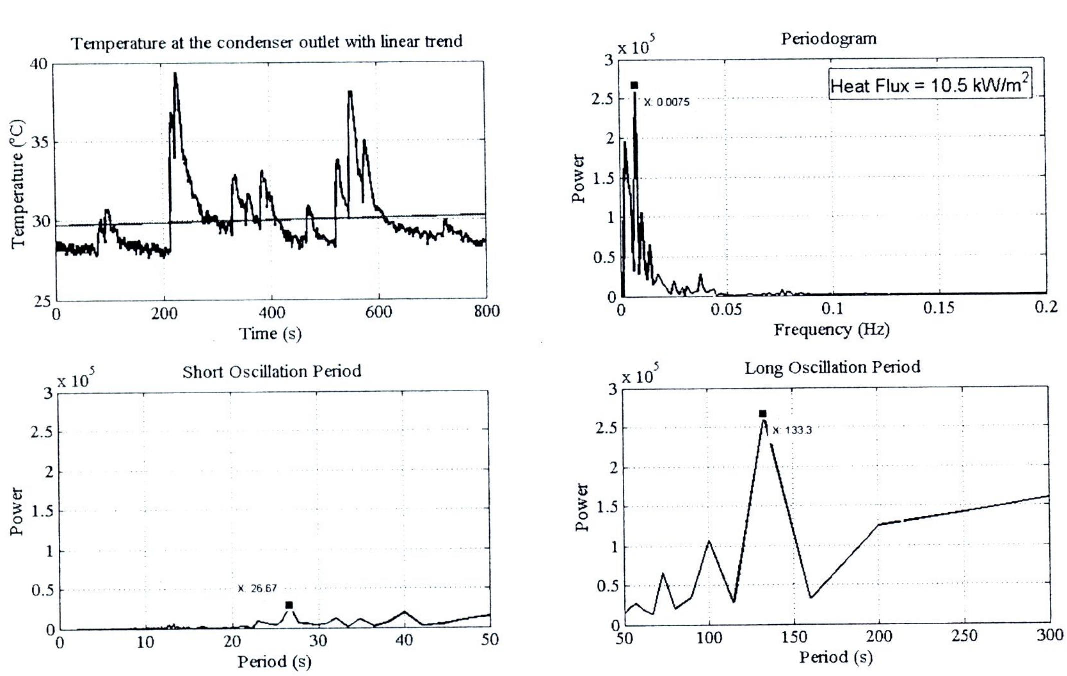

Fig. B3.2 FFT profile of temperature at the condenser outlet at 10.5 kW/m^2 heat flux

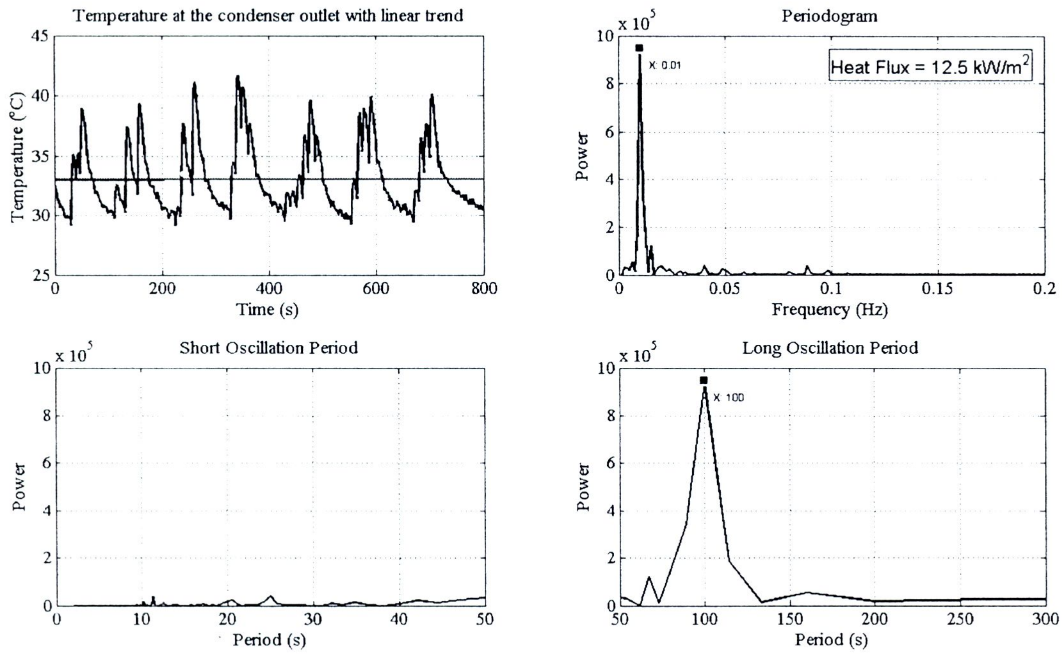

Fig. B3.3 FFT profile of temperature at the condenser outlet at 12.5 kW/m^2 heat flux

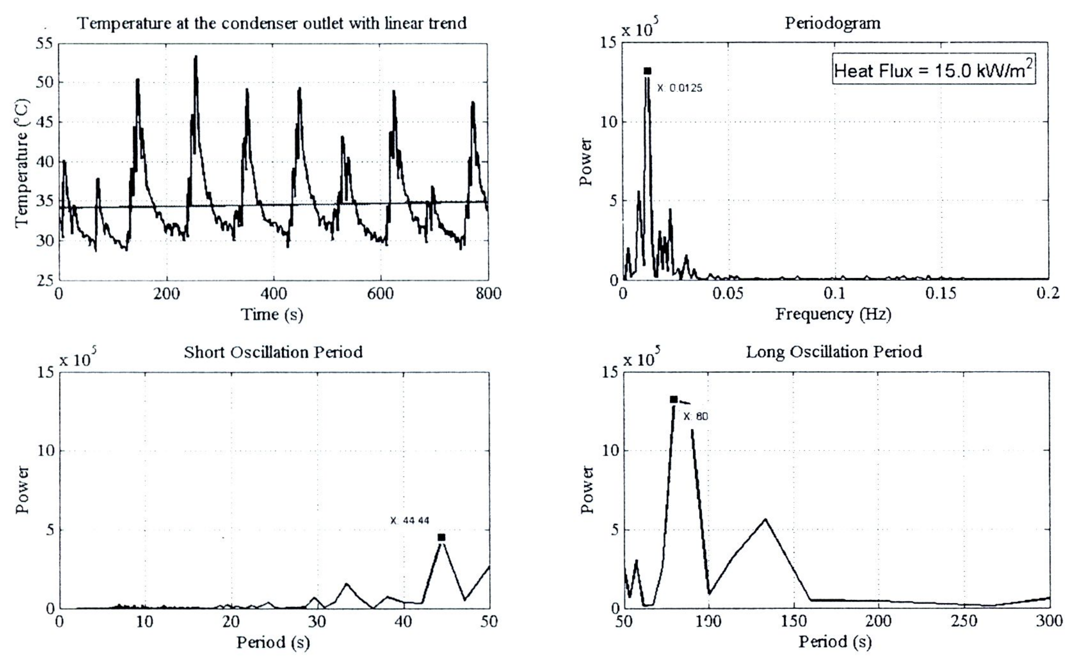

Fig. B3.4 FFT profile of temperature at the condenser outlet at 15.0 kW/m^2 heat flux

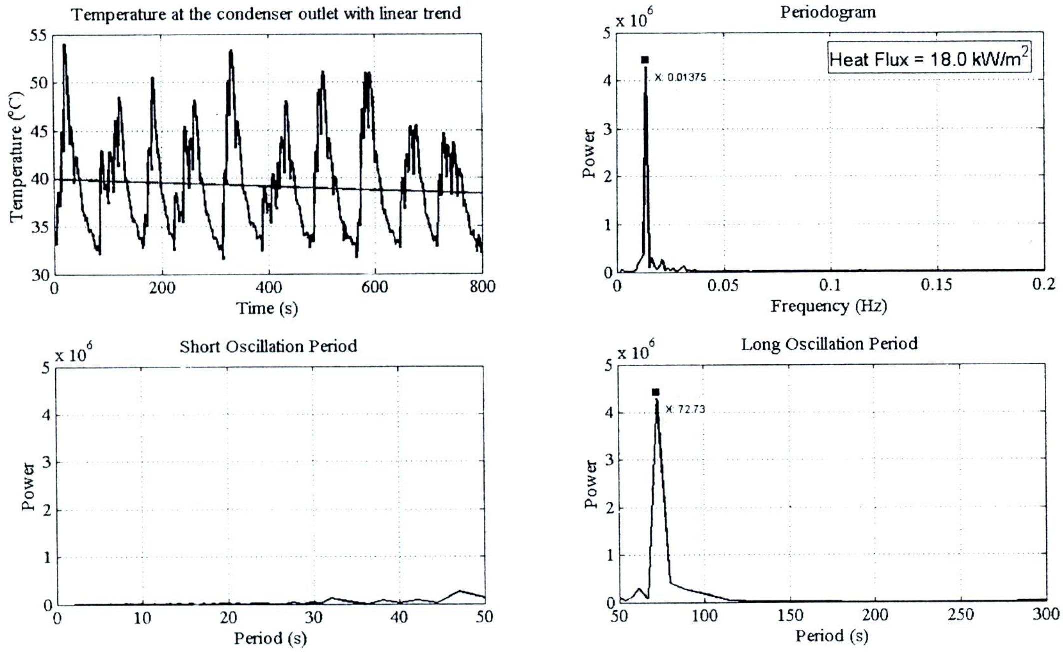

Fig. B3.4 FFT profile of temperature at the condenser outlet at 18.0 kW/m^2 heat flux

Appendix B.4 FFT profiles of differential pressure across the heater for the NCL#2

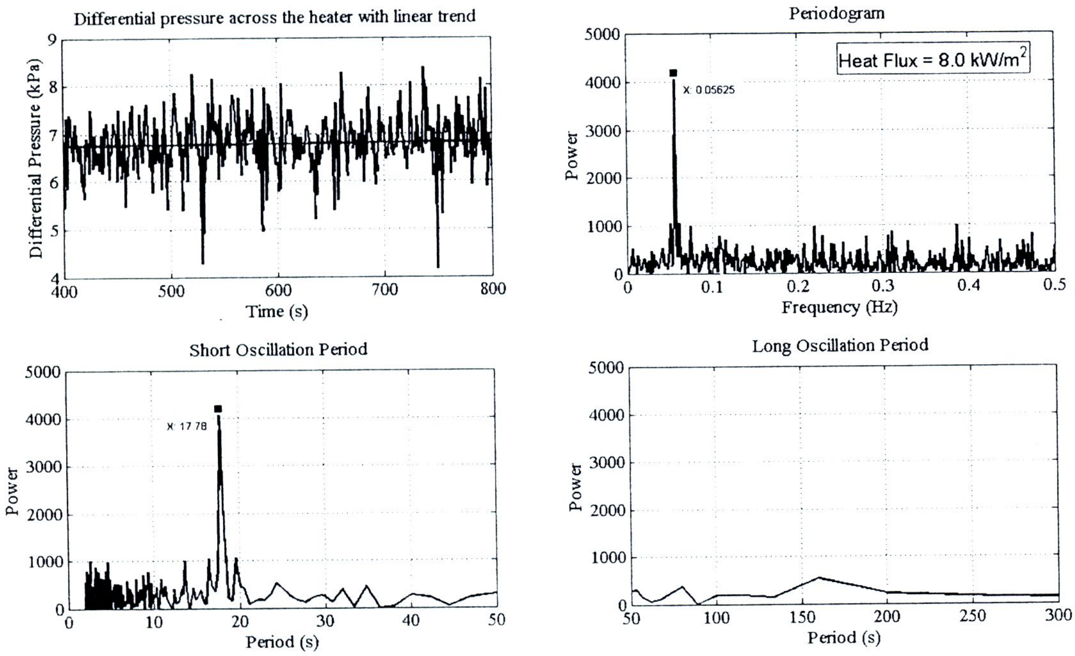

Fig. B4.1 FFT profile of differential pressure across the heater at 8.0 kW/m^2 heat flux

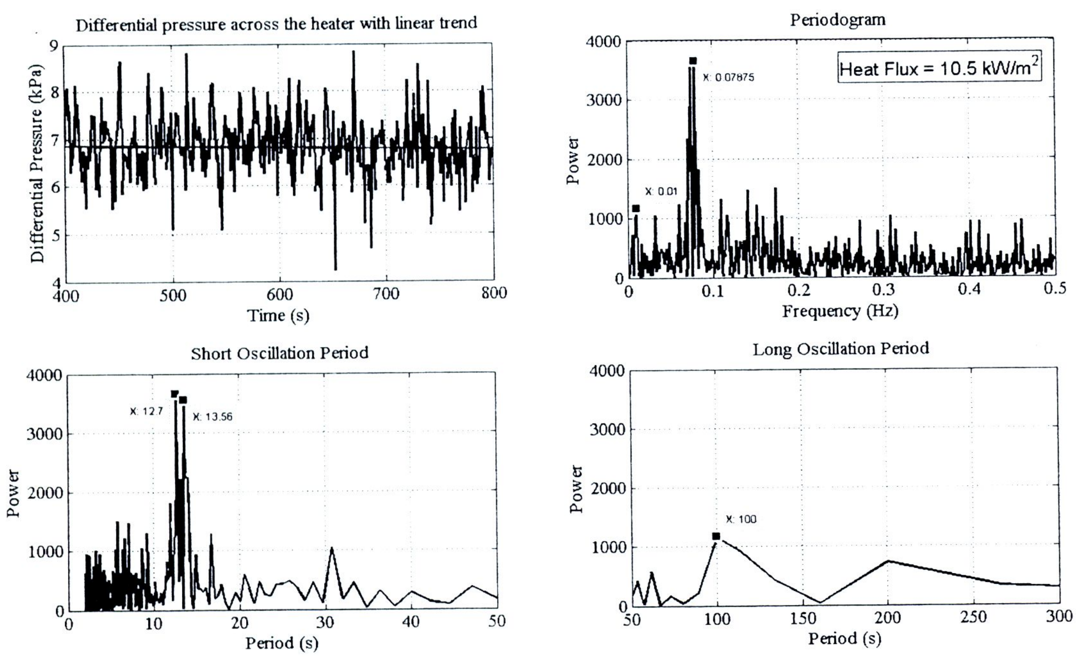

Fig. B4.2 FFT profile of differential pressure across the heater at 10.5 kW/m^2 heat flux

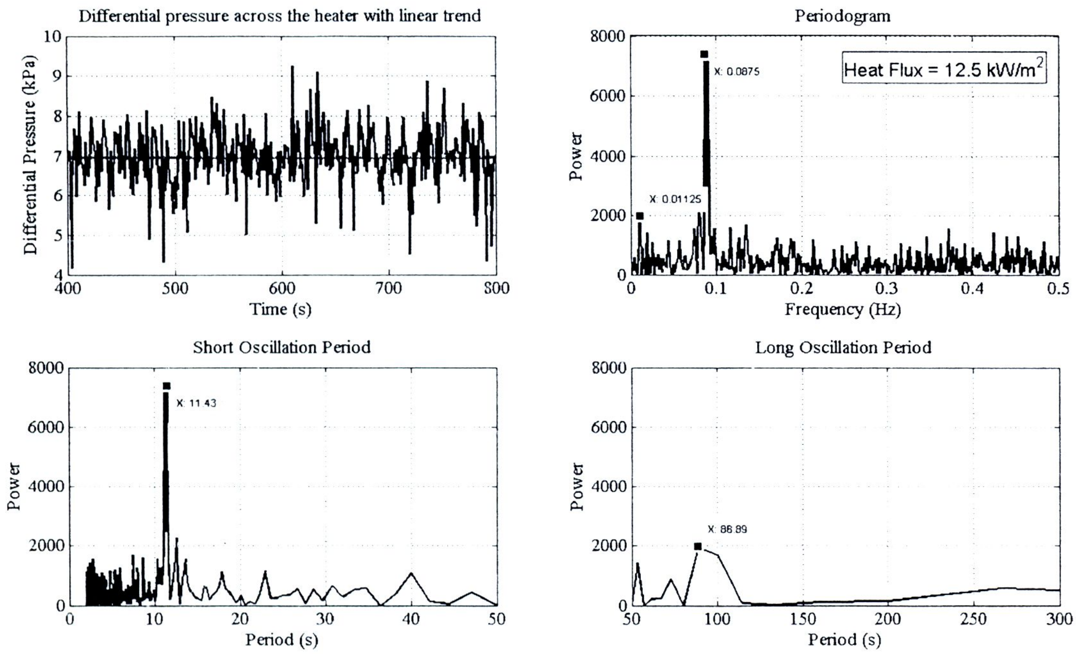

Fig. B4.3 FFT profile of differential pressure across the heater at 12.5 kW/m^2 heat flux

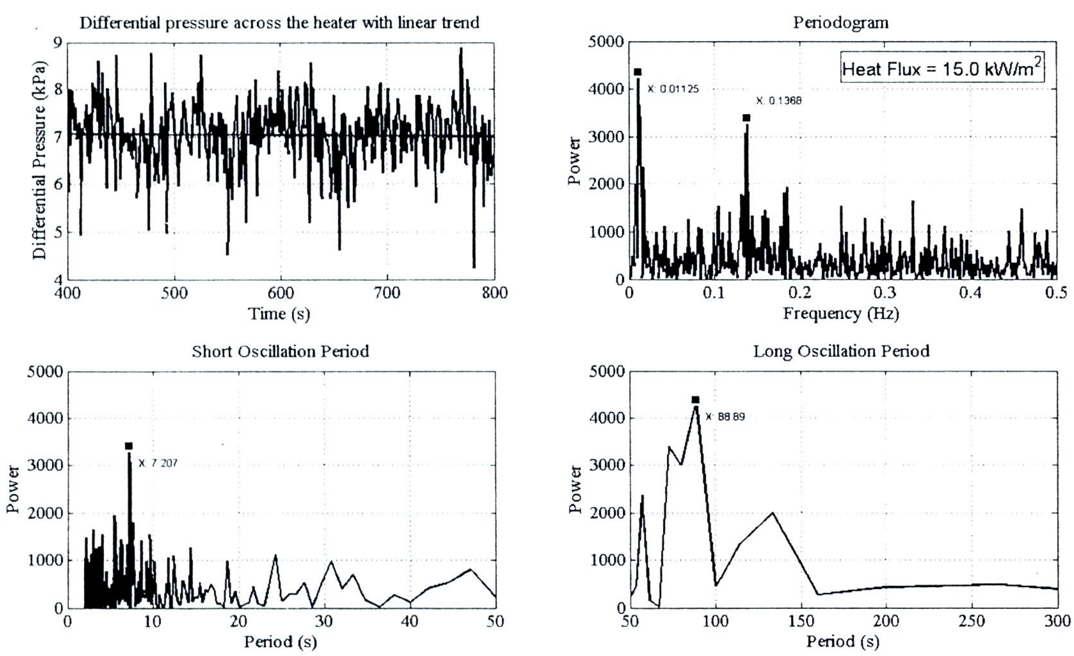

Fig. B4.4 FFT profile of differential pressure across the heater at 15.0 kW/m^2 heat flux

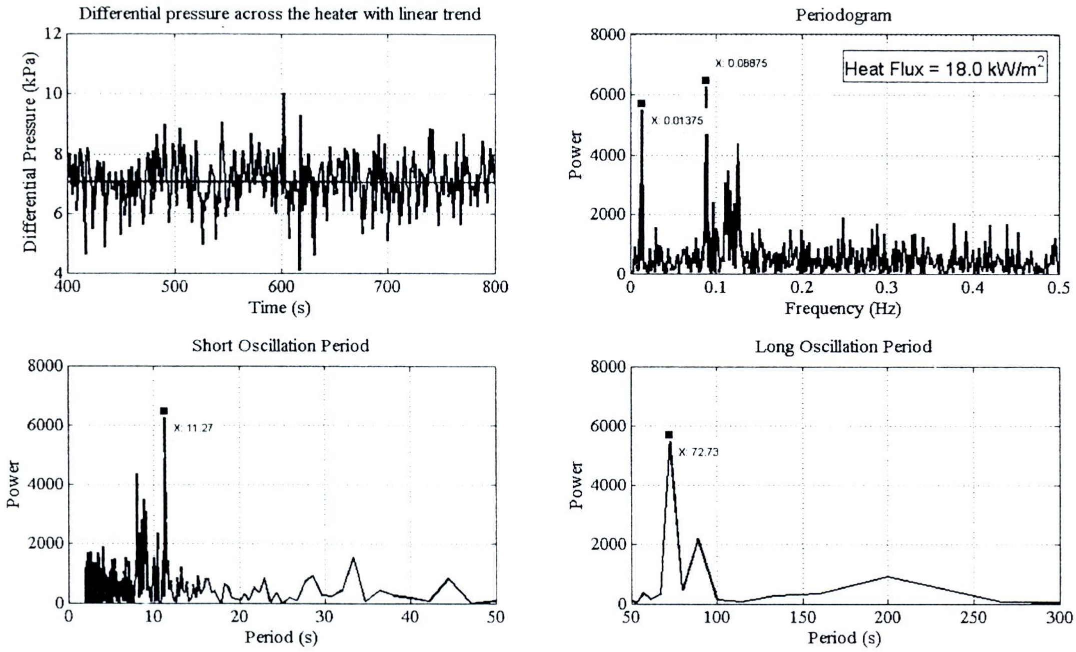

Fig. B4.5 FFT profile of differential pressure across the heater at 18.0 kW/m^2 heat flux

Appendix C Input file for the computer simulation

Detail of input file (Input.txt) used for computer simulation

Simulation of startup transient in Two-Phase flow ! Text (indicated as (1) in Fig. C.1)

&ISET ! Information about initial setup

IB=60, ! Number of mesh cell

FLB=1, FLT=1, ! Bottom and top boundary condition

! 1 = continuous boundary (rectangular loop)

! 2 = reflective boundary

! 3 = gradient free flow boundary

! 4 = constant pressure boundary

ITMAX=200, ! Maximum iteration

THSTAR=0.5, ! Void fraction for separate flow pattern

EPSL=1E-5, EPSG=3E-3, EPSD=0.5,EPSI=0.5,EPSP=0.5, ! Convergent criteria

THFLAG=.01,ETH=.1 &

&GRID ! Information about mesh cell (indicated as (2) in Fig. C.1)

DXI(1)=0.1, NDX(1)=60, ! Delta X (m)

ARIY(1)=0.0004, NARIY(1)=60, ! Area (m^2) in Y axis

ARIX(1)=0.0004, NARIX(1)=60, ! Area (m^2) in X axis

ARJ(1)=0.0004, NARJ(1)=60 & ! Area (m^2) at junction

&INIT ! Information about initial conditions

UGO(1)=0.00, NUG(1)=60, ! Vapor velocity (m/s)

ULO(1)=0.00, NUL(1)=60, ! Liquid velocity (m/s)

PO(1)=1.2e5, NPO(1)=60, ! Pressure (Pa)

THO(1)=0.0, NTH(1)=60, ! Void fraction

TLO(1)=303., NTL(1)=60, ! Liquid temperature (K)

TGO(1)=373., NTG(1)=60, ! Vapor temperature (K)

GRAVO(1)=9.8, NGRAV(1)=20, ! Gravity for vertical tube (upward flow)

GRAVO(2)=0.0, NGRAV(2)=10, ! Gravity (m/s^2) for horizontal tube

GRAVO(3)=-9.8, NGRAV(3)=20, ! Gravity for vertical tube (downward flow)

```
GRAVO(4)=0.0,        NGRAV(4)=10,         ! Gravity (m/s^2) for horizontal tube
TWO(1)=323.,         NTW(1)=60 &          ! Wall temperature (K)
&BOUND      ! Information for constant pressure boundary
PIN=1e5,             ! Pressure (Pa) at inlet
THOUT=0.0,           ! Void fraction at outlet
POUT=1e5 &           ! Pressure (Pa) at outlet
&RUNTIM     ! Information about run time
TMAX=2000.0,                          ! Maximum of run time
DT=1D-4,                              ! Normal time step (s)
DTMAX=1D-1, DTMIN=1D-9 &              ! Maximum and minimum time step (s)
&OUTPUT     ! Position of each gauge that used to display value on each graph
(indicated as (2) and (3) in Fig. C.1)
IPR(1)=61,IPR(2)=61,IPR(3)=10,IPR(4)=10,
IPR(5)=21,IPR(6)=32,IPR(7)=42, IPR(8)=31 &
&CONST      ! Constant value used in computer program
c(18)=0.79, c(20)=0.5, c(21)=1., C(29)=3., C(30)=1., C(31)=20., C(32)=0.45,
C(33)=0., C(34)=0., C(35)=1., C(36)=1., C(37)=0., C(38)=1., C(39)=1., C(40)=1.,
C(41)=0.1,C(42)=1D-4,C(43)=1.,C(44)=1.,C(45)=0.1,C(46)=0.,C(47)=1D-3,
C(48)=1., C(49)=0.1093, C(50)=-0.0785, C(51)=1.0, C(52)=0.246, C(53)=0., C(54)=1.,
C(55)=0., C(56)=1.0, C(57)=0., C(58)=0.,C(59)=0., C(60)=0.,
C(61)=1.0,                  ! Time for display value in screen
C(62)=0.0,  C(63)=2000.0,   ! Minimum and maximum time for each graph
C(64)=0.0,  C(65)=6.0,      ! Min and max height (indicated as (4) in Fig. C.1)
C(66)=2,   C(67)=0,   C(68)=0.10,   C(69)=0.15,   ! 1 = void fraction
C(70)=4,   C(71)=0,   C(72)=20.0,   C(73)=120.0,  ! 2 = pressure (MPa)
C(74)=4,   C(75)=0,   C(76)=20.0,   C(77)=120.0,  ! 3 = vapor temperature (C)
C(78)=2,   C(79)=0,   C(80)=0.1,    C(81)=0.15,   ! 4 = liquid temperature (C)
C(82)=4,   C(83)=0,   C(84)=20.0,   C(85)=120.0,
C(86)=4,   C(87)=0,   C(88)=20.0,   C(89)=120.0,
C(90)=4,   C(91)=0,   C(92)=20.0,   C(93)=120.0,
C(94)=1,   C(95)=0,   C(96)=0.0,    C(97)=0.1,
```

C(98)=0., C(100) = 0.0, C(101) = 0.0, C(102) = 0.05, C(103) = 3.083E8,

C(104) = 151.0, C(105) = 91.22, C(106) = 2.0, C(107) = 1, C(119) = 1000.3D6,

C(120) = 1000.3D6, C(131) = 0.0000134, C(132) = 0.285, C(133) = 14600.,

C(134) = 5710000., C(135) = 400.0, C(136) = 0.0, C(141) = 0.01, C(142) = 0.3,

C(143) = 1.0e6, c(145)=39.848 &

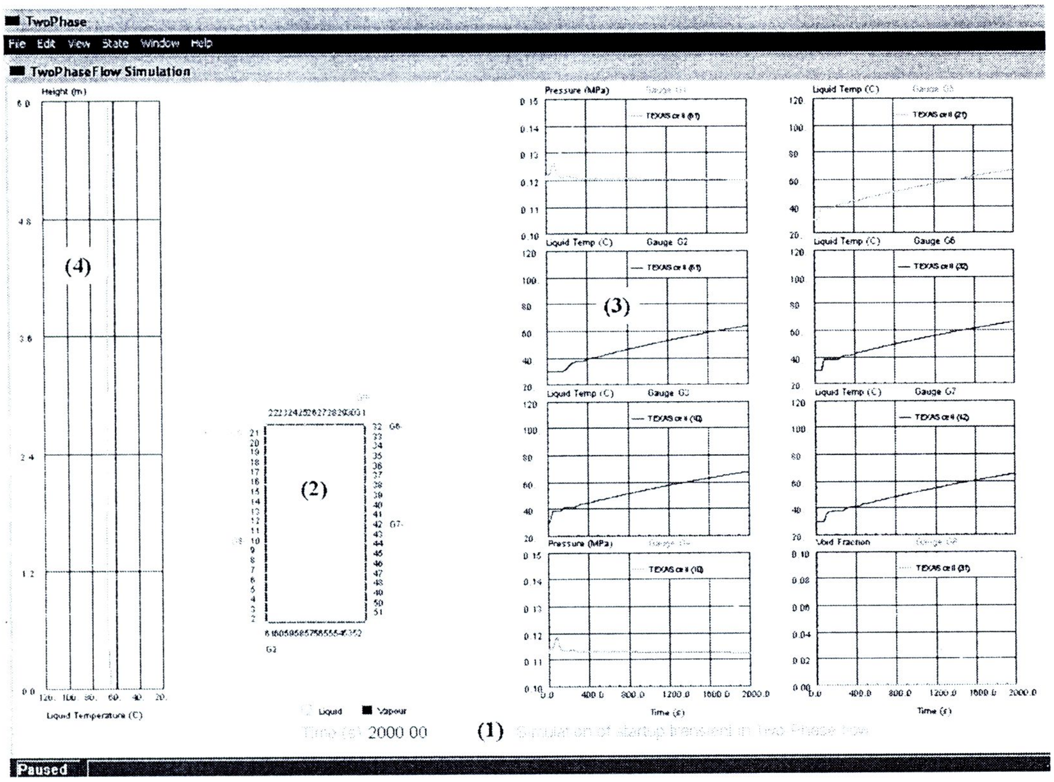

Fig. C.1 Computer program

Biography

Mr. Somchai Baotong was born on August 15, 1977 at Sisaket province, Thailand. He got Bachelor degree with second class honors from the department of physics, faculty of science, Ubon Ratchathani University in 2000. After graduated he worked as assistance researcher at nuclear engineering material laboratory, department of nuclear technology, faculty of engineering, Chulalongkorn University for 1 year. He got Master degree from department of nuclear technology, faculty of engineering, Chulalongkorn University in 2003. He worked as engineer in hard disk drive industry for 3 years before he began to study in the Doctoral degree at the department of nuclear technology, faculty of engineering, Chulalongkorn University in June 2006.