INSTRUCTION cum EXPERIMENTS MANUAL

FOR

POOL BOILING HEAT TRANSFER APPARATUS MODEL TH-111

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1. WARRANTY CERTIFICATE

Supply of **POOL BOILING HEAT TRANSFER APPARATUS TH-111**

The above instrument is warranted to be free from defects in workmanship and material and if it proves so defective within 15 (Fifteen months) calendar months from the date of shipment to the original purchaser, named above it shall be repaired or replaced free of. charge provided

The Purchaser sends promptly to M/s. SCI-TECH ENGINEERING PRIVATE LIMITED

102, Regency, New Link Road, Dahisar (West), Mumbai 400 068. INDIA, notice of defect and satisfactory proof thereof as abolishing that the instrument has been properly maintained and operated within the limits of rated capacity and normal usages, and

- Assumes the obligation of all expenses of returning the defective instrument, properly packed to the Factory at the address given in (a) above, if required.
- On parts of products incorporated in the instrument but not manufactured by M/s. SCI-TECH ENGINEERING PRIVATE LIMITED, this warranty is limited to extending to the purchaser the same warranty as given by the supplier of such part or products.

This guarantee dose not covers consumable parts such as Bulbs, Fuses, and Rubber Seals etc.

Under the circumstances shall M/s SCI-TECH ENGINEERING PRIVATE LIMITED, have any liability whatsoever for loss of use or for any indirect or consequential damages.

We can only undertake to send our men to a distance to investigate and put right alleged defects on the distinct understanding that we are paid for their time and expenses in every case.

M/s. SCI-TECH ENGINEERING PRIVATE LIMITED decision about repairing or replacing the equipment or its parts will be final and binding on all concerned parties.

Unless superseded or in contractual form, this warranty is made expressly in lieu of all the other liabilities and obligations on our part.

For SCI-TECH ENGINEERING PRIVATE

2. Description

2.1 Introduction

The pool boiling heat transfer apparatus is used here to calculate critical heat flux (CHF) of the test specimen. Critical heat flux (CHF) is an important criterion in nuclear reactor safety and the efficiency of boiling heat transfer. This parameter is known to be dependent of the surface roughness and the wettability of a material that is in contact with boiling fluid. Generally, CHF enhances with increasing surface roughness and wettability.

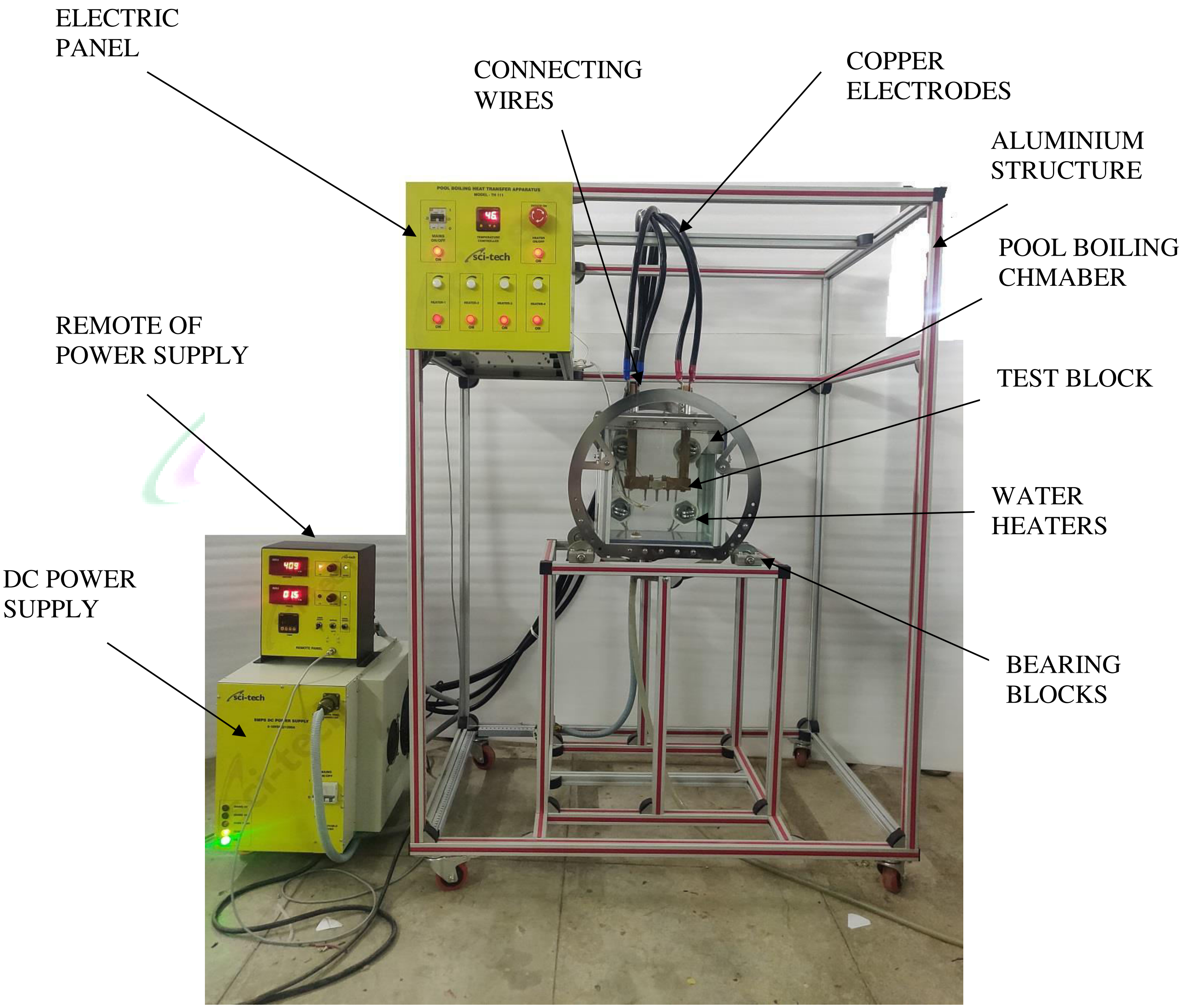
The unit comprises of pool boiling chamber made of polycarbonate equipped with water heater, copper blocks, PEEK insulation block, copper electrodes & test specimen.

For calculating CHF of each test specimen unit comes with DC power supply of 10volts & 1200A, for supplying power to specimens through copper electrodes inside pool boiling chamber.

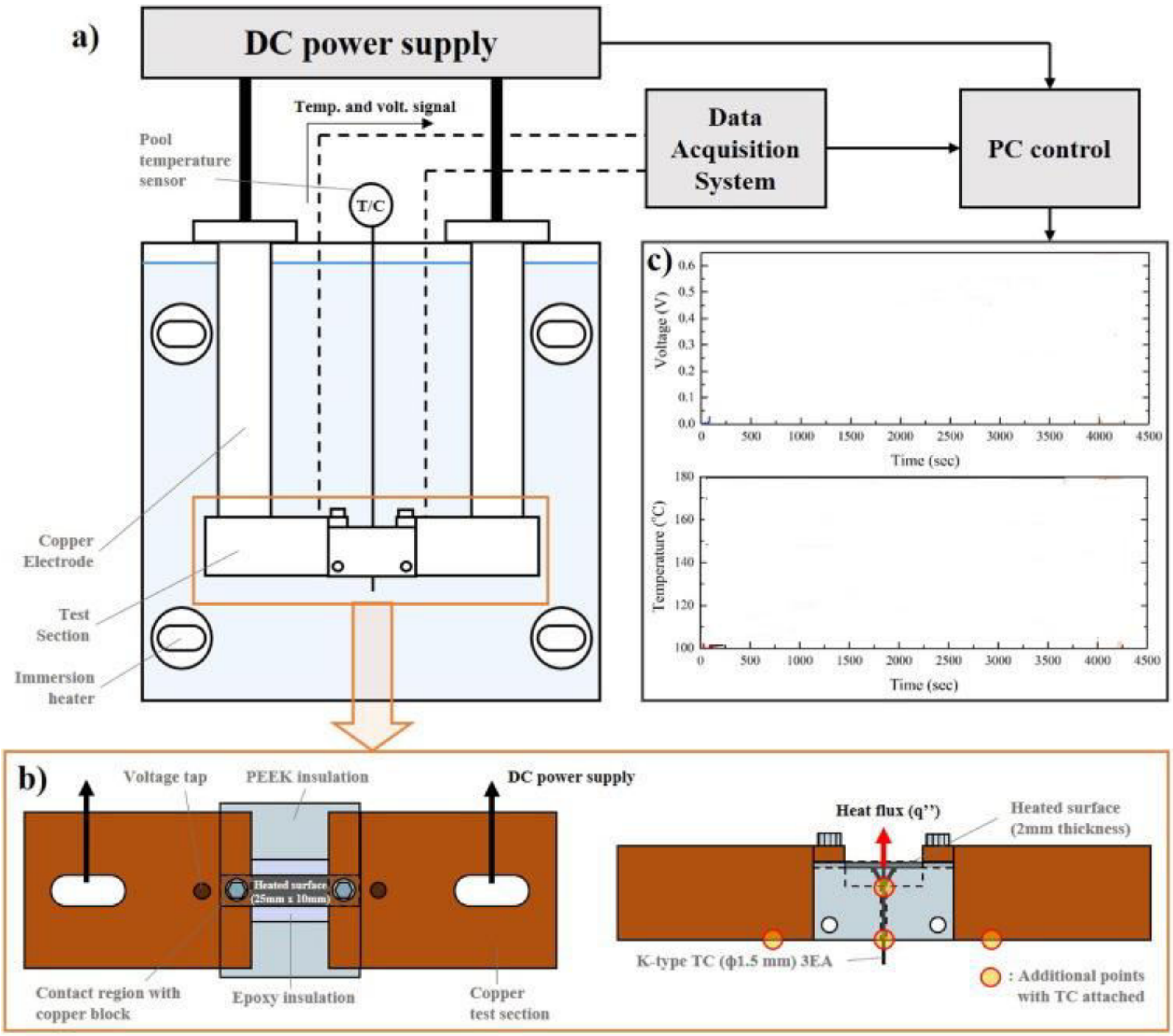
For analyzing data and controlling voltage of power supply DAQ device is available with data acquisition software which can connect to laptop/computer via USB cable.

For controlling heater power regulator is mounted on panel, for visualizing power supply data remote control is available & to change power manually via POT. More description of components we will see below.

2.2 Pictorial Description



2.3 Description of the process



Pool boiling heat transfer apparatus Model TH-111, is designed by **SCI-TECH** to study characteristics & parameters of critical heat flux (CHF) of different surface test specimens. The objective of this unit is to calculate CHF of bare specimens and oxidized specimens.

- **Sample preparation:** In this unit test samples were using of two types of same grade stainless steel 304L (certified) as NS (Non treated specimens) & OS (oxidized specimens). The non-treated specimen was mechanically polished using different grades of ultrafine sandpaper (i.e 320, 600, 800) so we have three types of NS specimens. The oxidized specimens were prepared as follows: non treated specimen was put into a furnace set to target temperatures of 300, 450 & 600 deg C, respectively, and gradually heated up. The average heating rate was about 2-2.5 ^{o}C/sec. the furnace maintained at a given temperature condition for 10min, and then slowly cooled down to about 30 ^{o}C. the average cooling rate was about 2-3 ^{o}C/min. Finally, three kinds of oxidized test specimens obtained as minimum furnace temperature was 300 ^{o}C and higher furnace temperature 600 ^{o}C. In this way we have prepared all test specimens as NS (fresh) no treated & OS oxidized surface.eg OS-SP320(450 ^{o}C) indicated test surface grounded with grade-320 sandpaper & oxidize at 450 ^{o}C. eg, as B-SP320 indicated test surface grounded with grade 320 sandpaper only.

- **Experimental setup:** A schematic of pool boiling unit and design of test section used in the study are shown in above figure 2. The experimental procedure for pool boiling is starts with test specimen preparation as already discussed in previous paragraph. Next step is to fill distilled water in pool boiling chamber and heat the distilled water until saturation temperature of water it will take approximately 60min for saturation from its environmental temperature.

After heating the water test specimen of NS or OS fitted between test copper blocks, insert into pool boiling chamber and clamp it with copper electrodes and top cover of chamber. Now we have to supply DC power to the specimen through electrode so set voltage and current in remote control of power supply and start the experiment.

For controlling and visualizing electric panel is situated at left top corner and DAQ device is connected with PC via USB which shows the all data in DAQ software.

The length, width, and thickness of test material were 45, 10, and 2 mm, respectively. Heat transfer surface area was 25×10 = 250 mm2 because rest 10 mm of both sides were connected with copper electrodes and copper cover for electrical contact. Polyether ether ketone (PEEK) and epoxy were used for thermal and electrical insulation. A K-type thermocouple was attached underneath the samples to measure inner wall temperature. Voltage taps were attached to the Allen screws at each side to measure voltage drop.

2.4 Specifications

The elements of **Pool boiling heat transfer apparatus** listed below:

- Pool boiling chamber:
  - Size: 300mm x 300mm x 300mm
  - Material: Polycarbonate 8mm thick
- Immersion Heaters:
  - Type: U type cartridge water heater continuously adjustable.
  - Material: S.S304
  - Capacity: 500 watts → 02nos.
  - Capacity: 1000 watts → 02nos.
- Test section:
  - Copper blocks → 02nos
  - Copper cover → 02nos
  - Polyether ether ketone PEEK block → 01nos
  - Test specimen:
    - Material: Stainless steel grade 304L
    - Size: L-25mm x W-10mm x T-2mm
    - Quantity: Each 10 with different surface finish and NS & OS
- DC power supply:
  - Type: Switched mode power supply

- Output: 0-10volts & 1200A DC
- Regulation: 0.5% to 1% at full load
- Efficiency: 85% - 95% at full load
- Cooling: forced air cooled
- Remote control: Digital voltmeter & ammeter with 3m flexible connection cable from main power supply unit.

➢ Data acquisition device:

- Make: National Instruments
- Model: NI USB 6001
- Inputs: 8 analog input
- Output: 2 Analog output

➢ Test matrix:

- Non treated specimens:
  - NS-320, NS-600, NS-800 (Bare specimens' ground with sandpaper grade 320, 600, 800 respectively)
- Oxidized specimen's:

	300^{o} C	450^{o} C	600^{o} C
320 Sand paper	OS-SP320(300^{o}C)	OS-SP320(450^{o}C)	OS-SP320(600^{o}C)
600 Sand paper	OS-SP600(300^{o}C)	OS-SP600(450^{o}C)	OS-SP600(600^{o}C)
800 Sand paper	OS-SP800(300^{o}C)	OS-SP800(450^{o}C)	OS-SP800(600^{o}C)

2.5 Dimension & Weights

- Process unit:
  - Dimensions: 1200 x 800 x 1600 mm (LxWxH) approx.
  - Weight: 120 kg. approx.

- DC power supply:
  - Dimensions: 2400 x 1500 mm approx.
  - Weight: 45Kg. approx

2.7 Required services

- Power supply: 220volts, 50Hz, Single phase for process unit.
- Power supply: 415volts, 50Hz, Three phase for DC power supply.

3. Installation Procedure

3.1 Process unit installation:

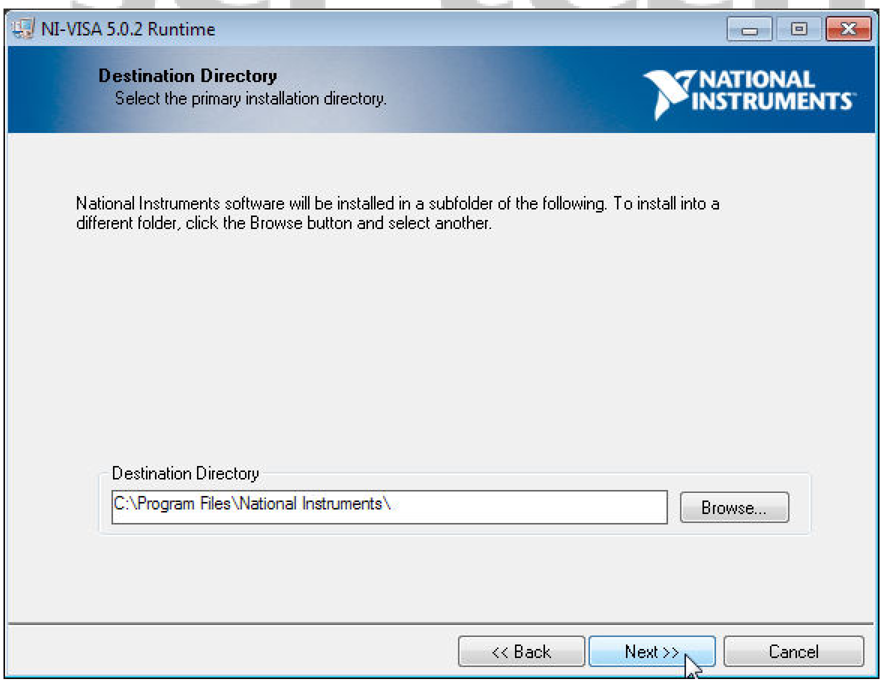
1. Remove the packing material and clean the components with dry clothes.
2. Please check the components as per enclosed component list and given specifications.
3. Keep the trainer on rigid surface
4. Fill the pool boiling chamber with distilled water.
5. Provide single phase 220 V AC supply at 50 Hz Frequency & with proper Earthing/Grounding to the trainer.
6. Provide single phase 415 V AC supply at 50 Hz Frequency & with proper Earthing/Grounding to the Power supply unit.
7. Switch ON the mains for checking proper supply of electricity.
8. Connect flexible pipes in drain of pool boiling chamber.
9. Installation is finish and ready for operation.

We hope that you enjoy using this experimental unit from SCI-TECH educational trainers' range & wish you success in your important task of introducing students to the fundamentals of technology.

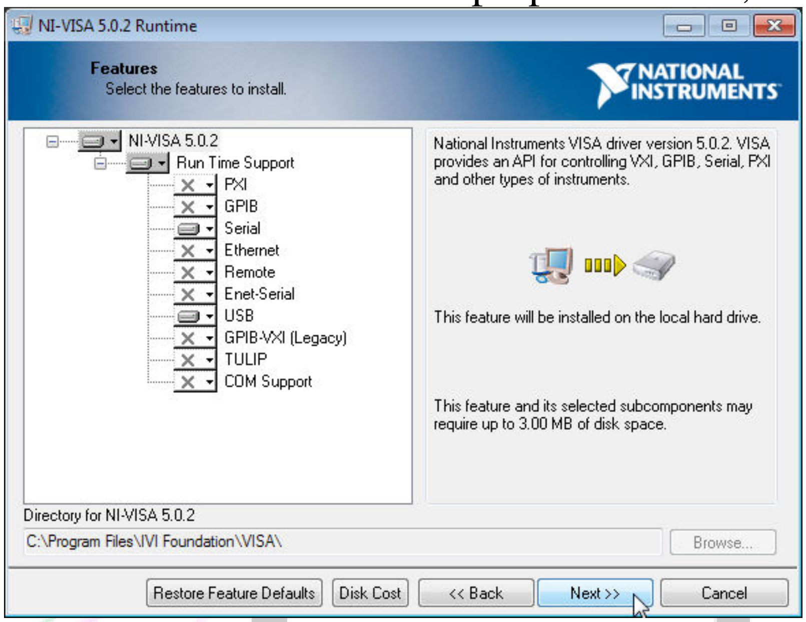
3.2 Data Acquisition software installation:

➢ Installation of NI VISA 1700:

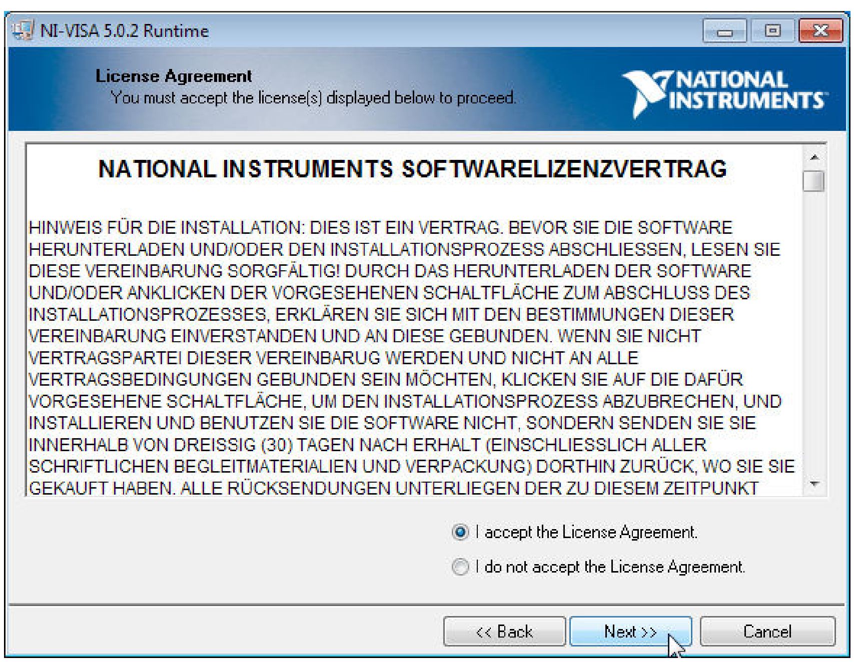
Click “Next”



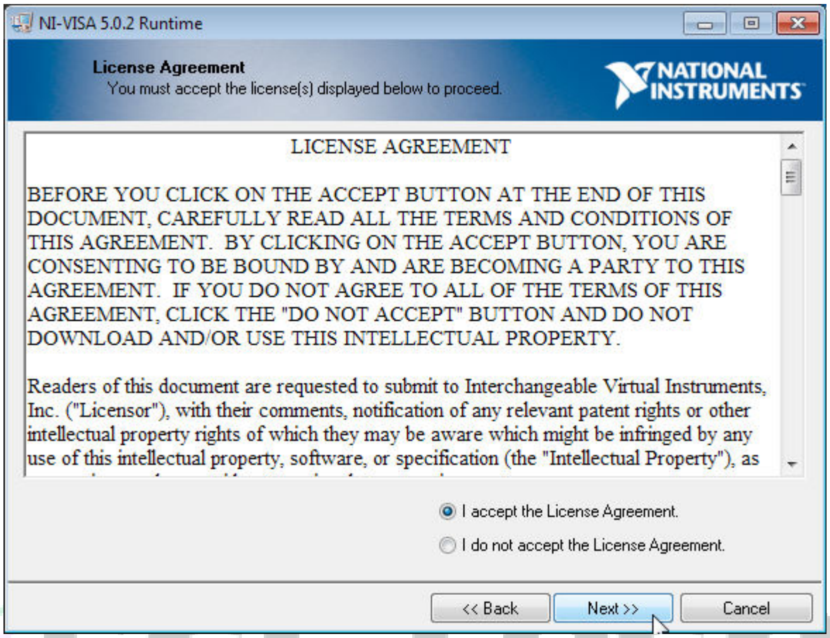
Its recommended to install NI-VISA to the proposed folder, click “Next”



In this screen the required components are being selected. USB is required for the Beam Profiler control, Serial (RS232) for control of the translation stage used for M²measurements.



Please read the Software License Agreement carefully, choose "I accept" and click "Next"



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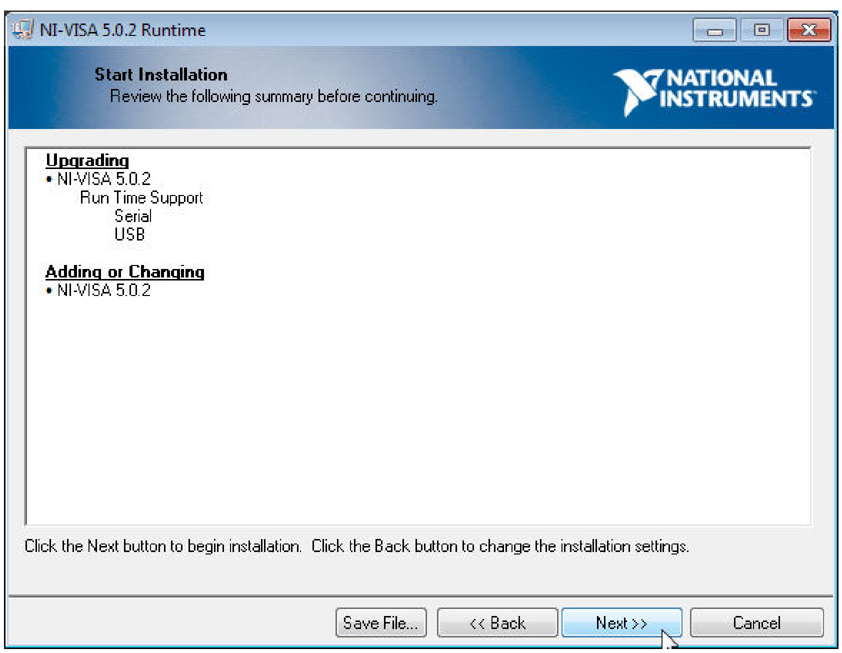
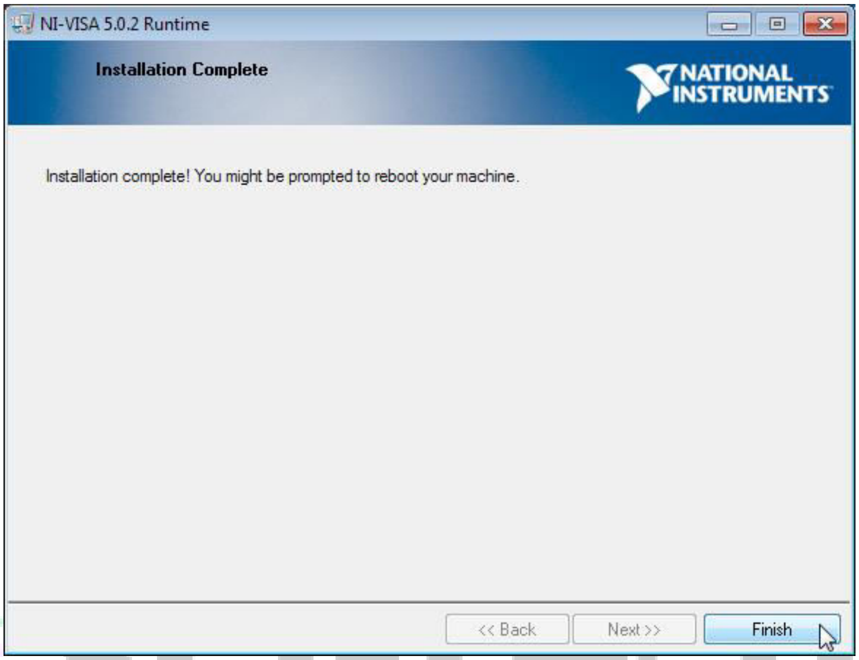
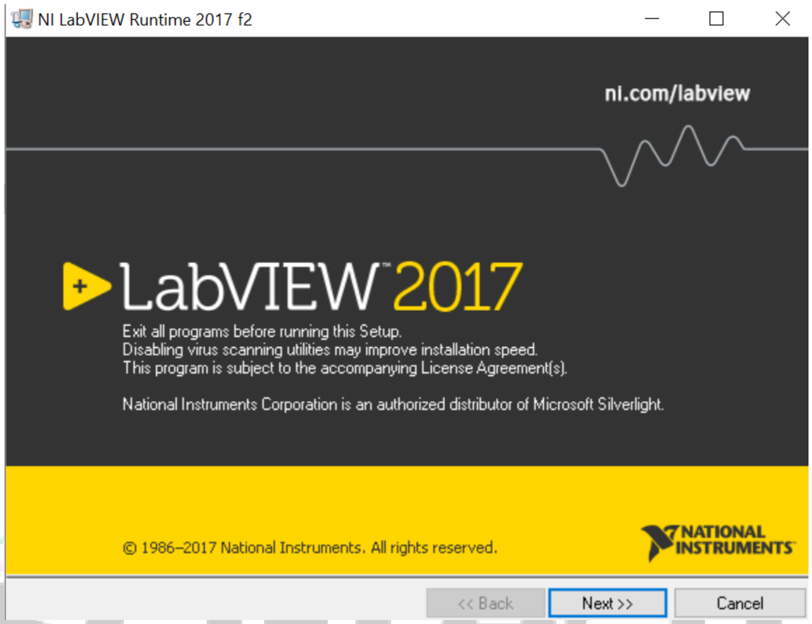


Click "Next", the software installation starts and may take a few minutes.

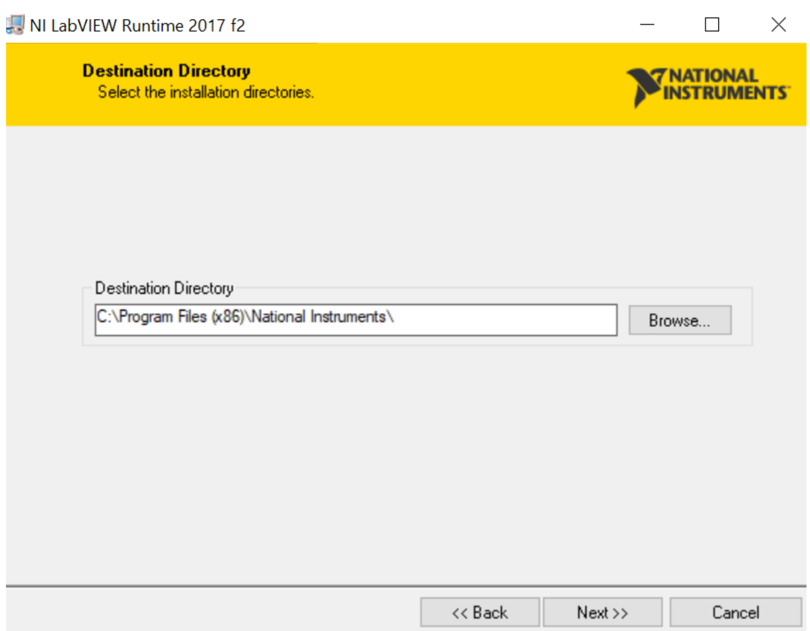


Click 'Finish'. The installation has completed successfully.

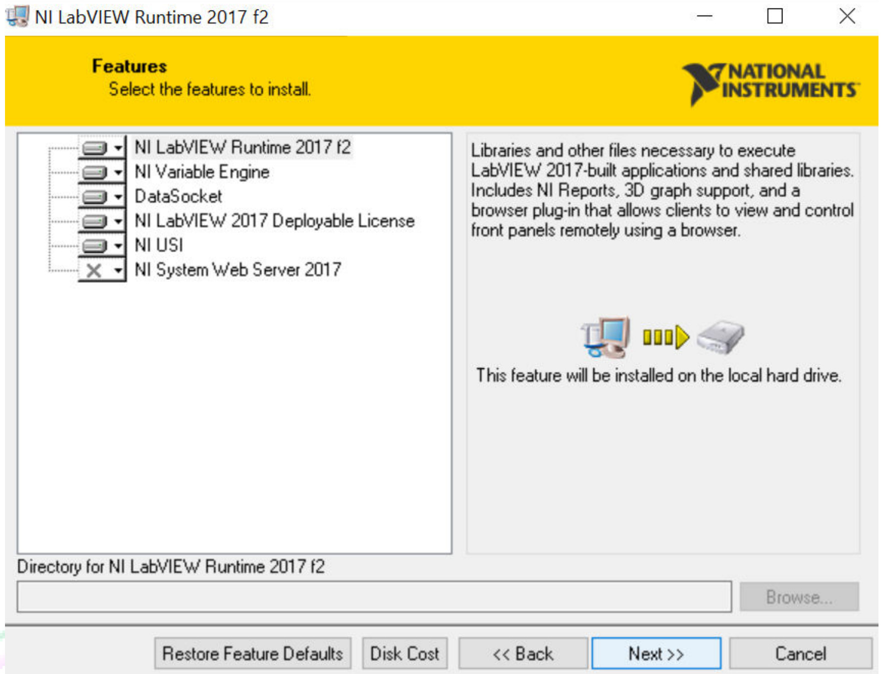
➢ Installation of runtime engine 2017:



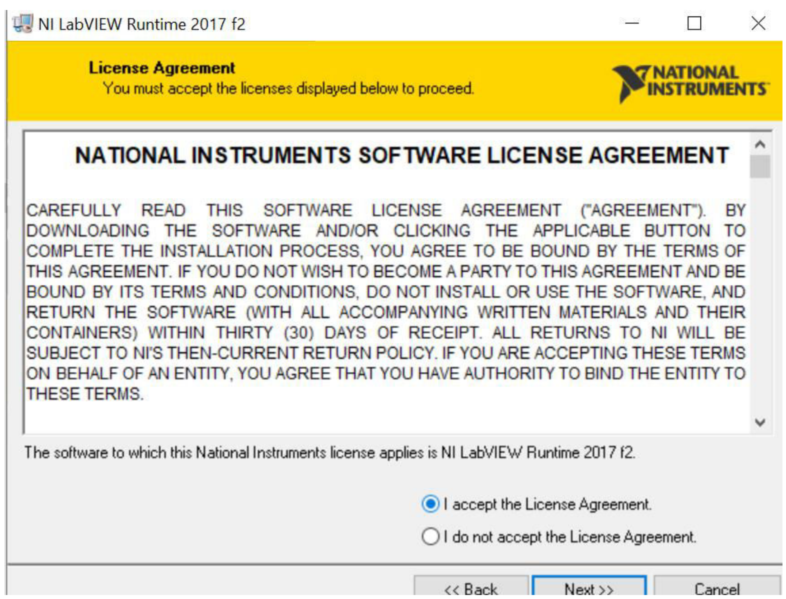
Click "Next"



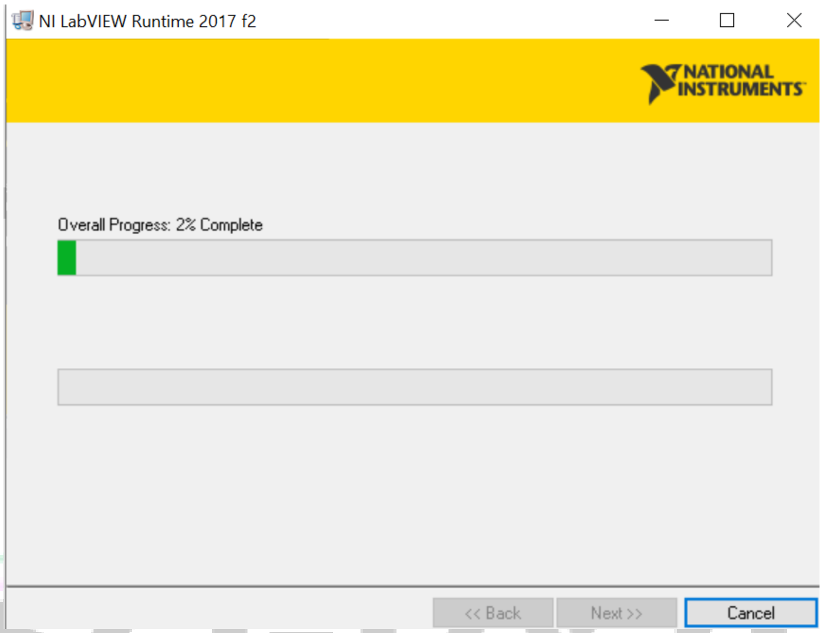
Its recommended to install Runtime to the proposed folder, click “Next”



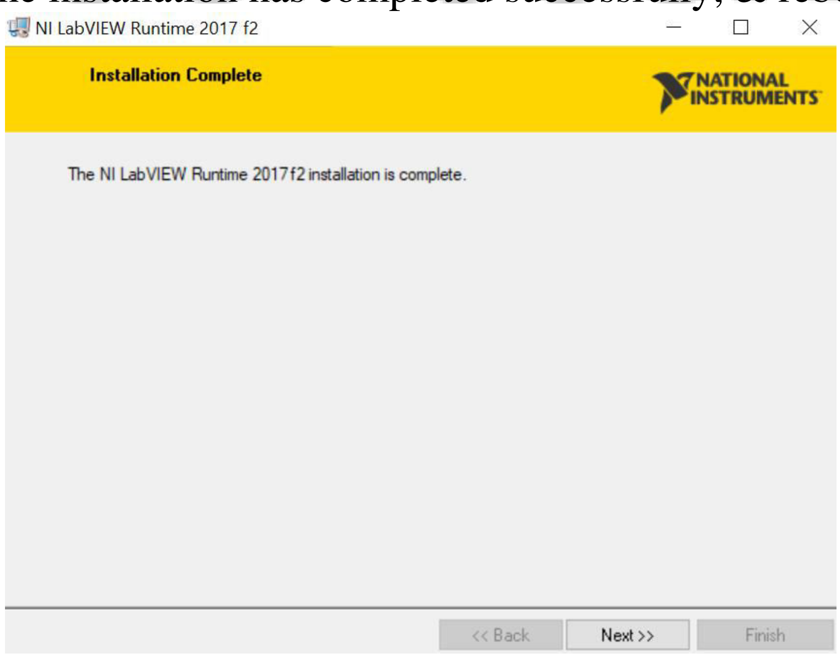
Please read the Software License Agreement carefully, choose "I accept" and click "Next"



Click "Next", the software installation starts and may take a few minutes.

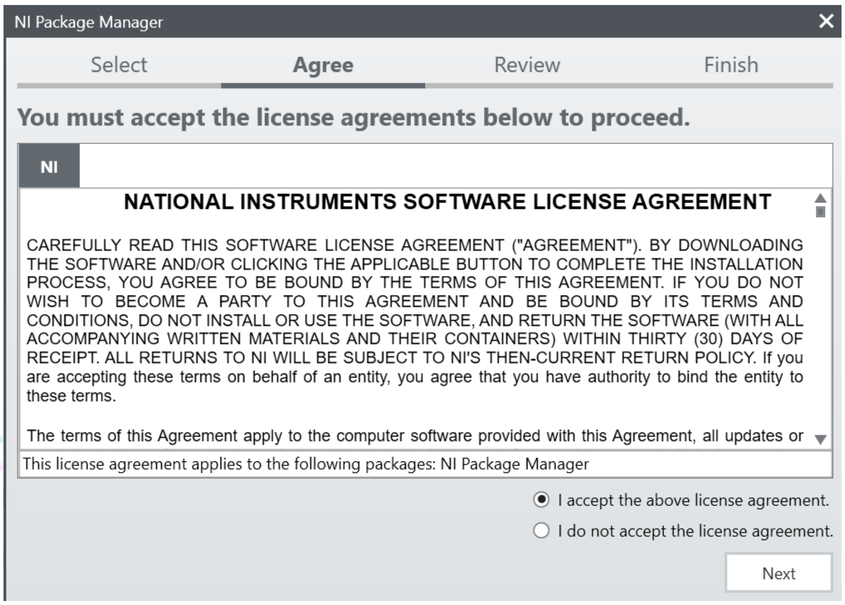


Click 'Next'. The installation has completed successfully, & reboot the device.

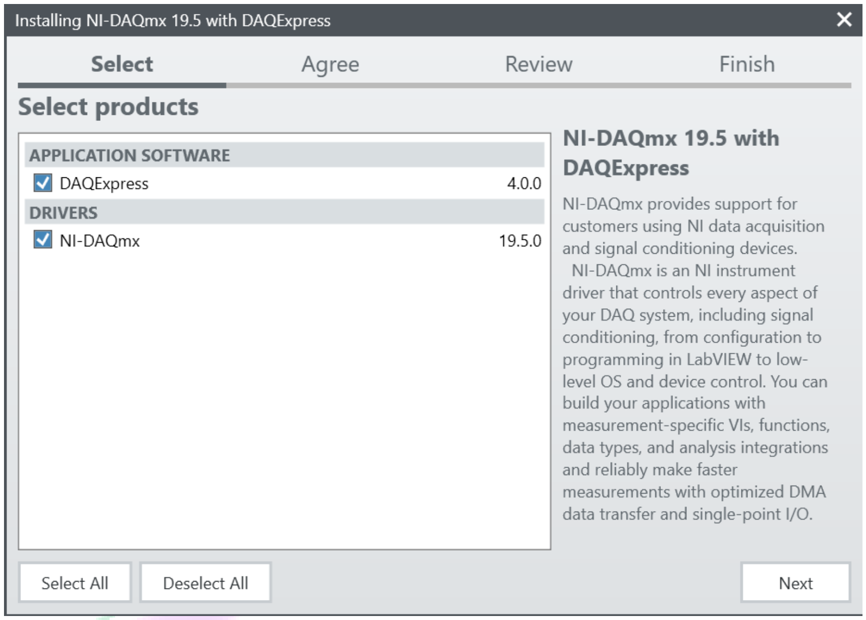


➢ Installation of DAQ mx:

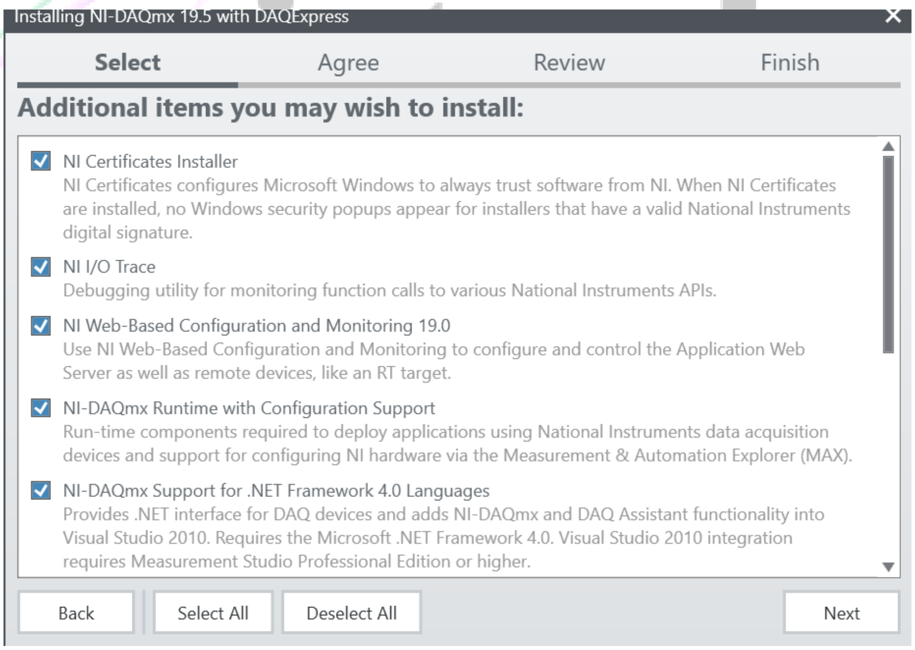
Please read the Software License Agreement carefully, choose "I accept" and click "Next"



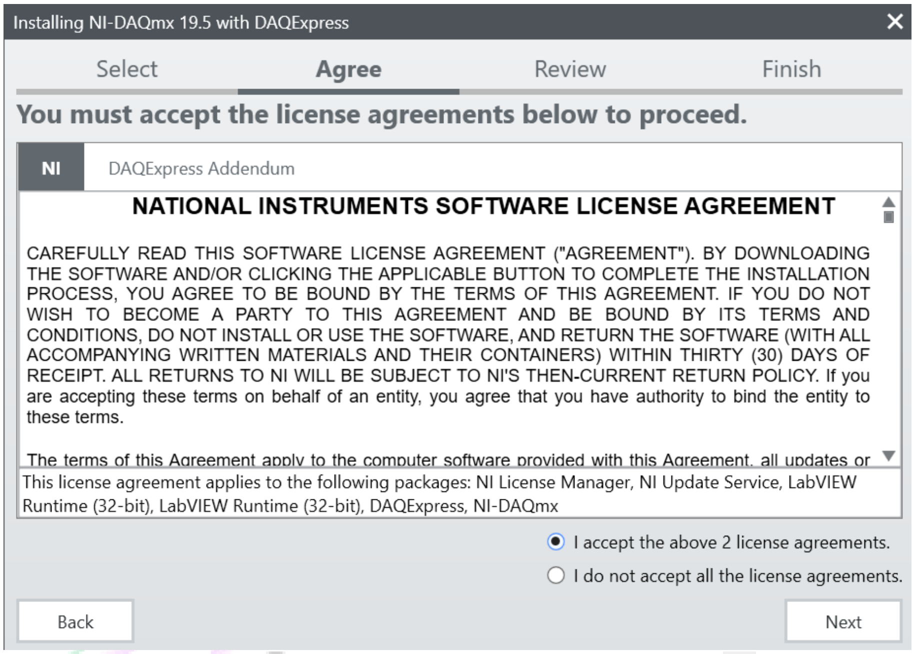
Select product to install and click “Next”



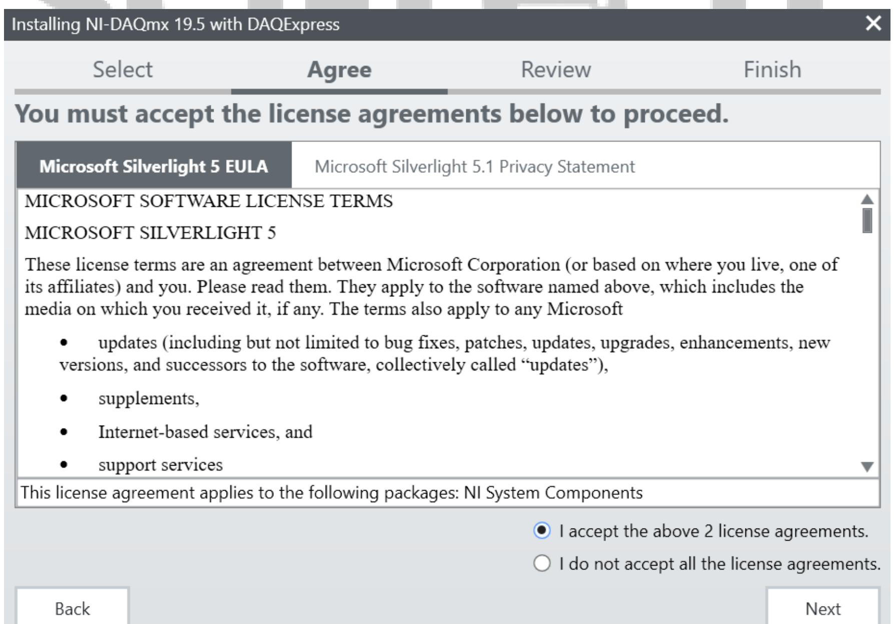
Select additional items to install and click “Next”



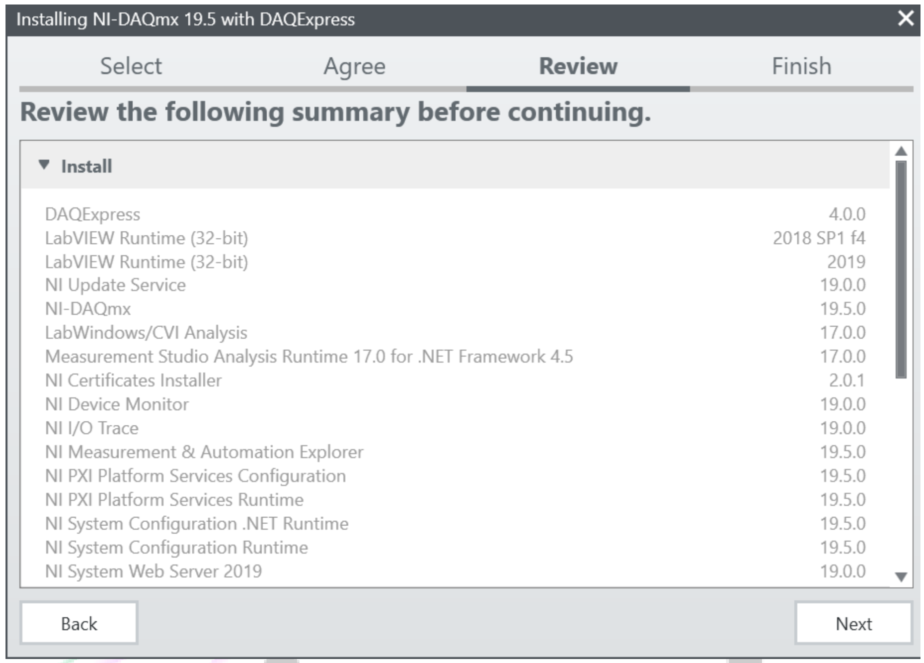
Please read the Software License Agreement no 01 carefully, choose "I accept" and click "Next"



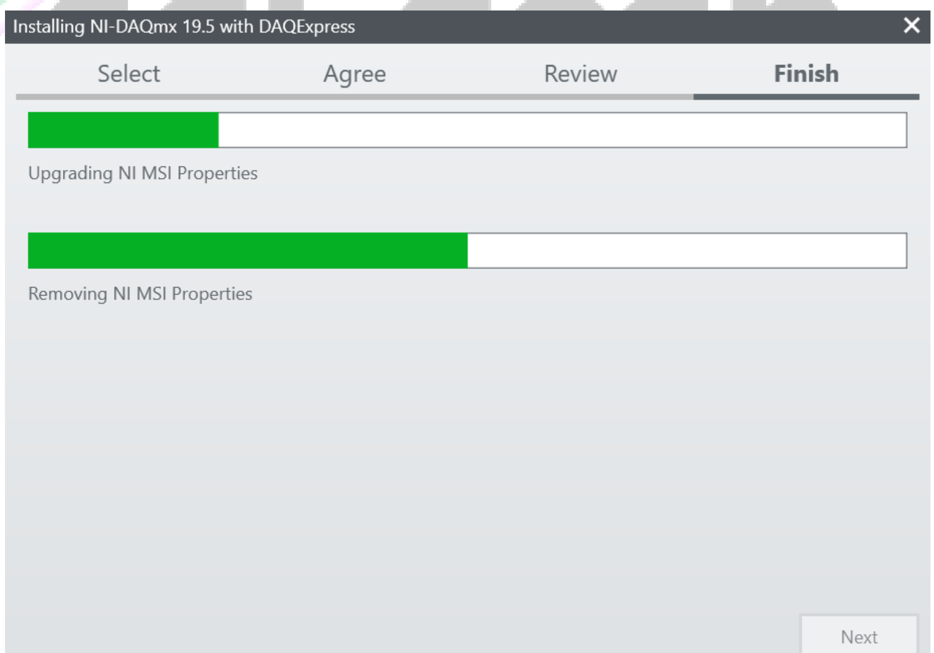
Please read the Software License Agreement no 02 carefully, choose "I accept" and click "Next"



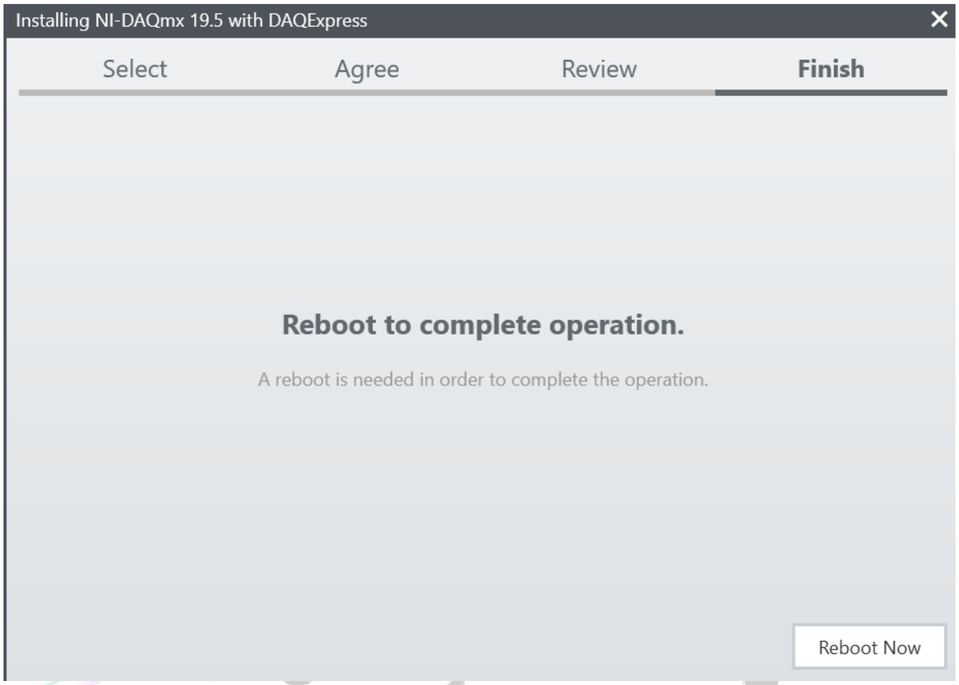
Please review the items which was select to install and click "Next"



Installation has been start & will take some time to finish.



After completing installation Reboot your device.

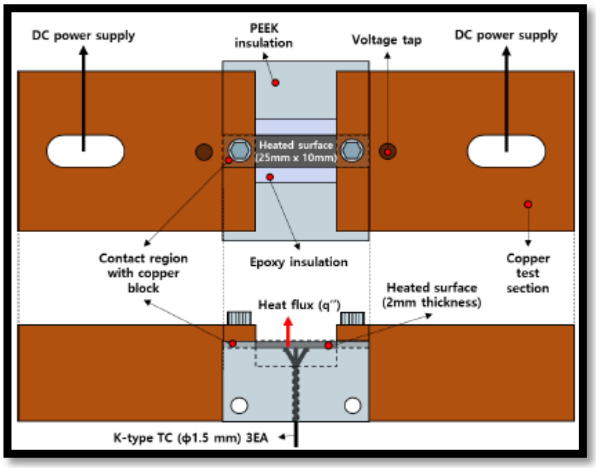


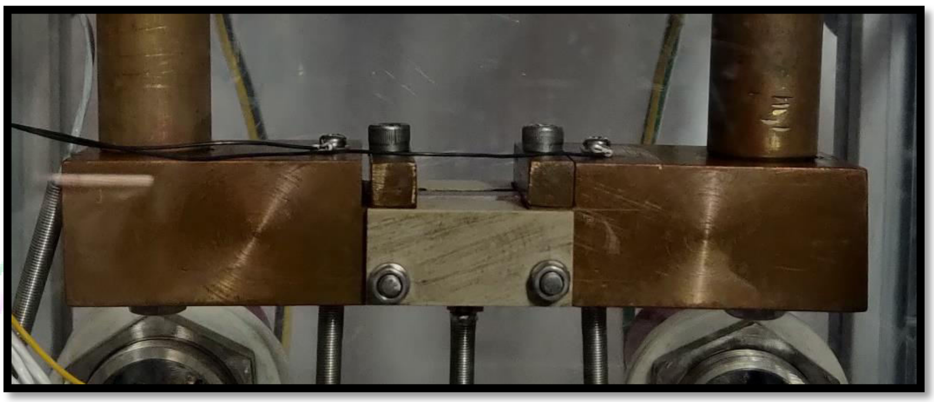
4. System description

4.1 Components of system

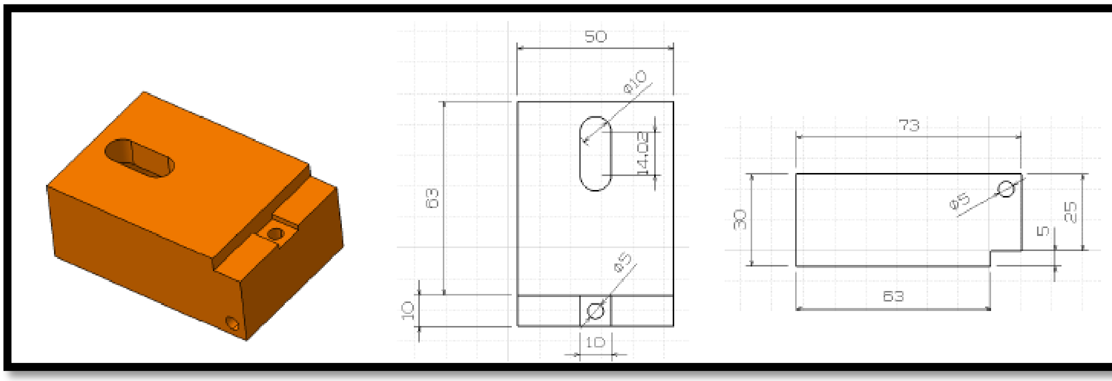
1. **Base stand –** it is made up of aluminum structure and as per the system configuration. All components are mounted on base stand.

2. **Test Section:** It consists of copper blocks with insulating material and test specimen which required for experimental setup.

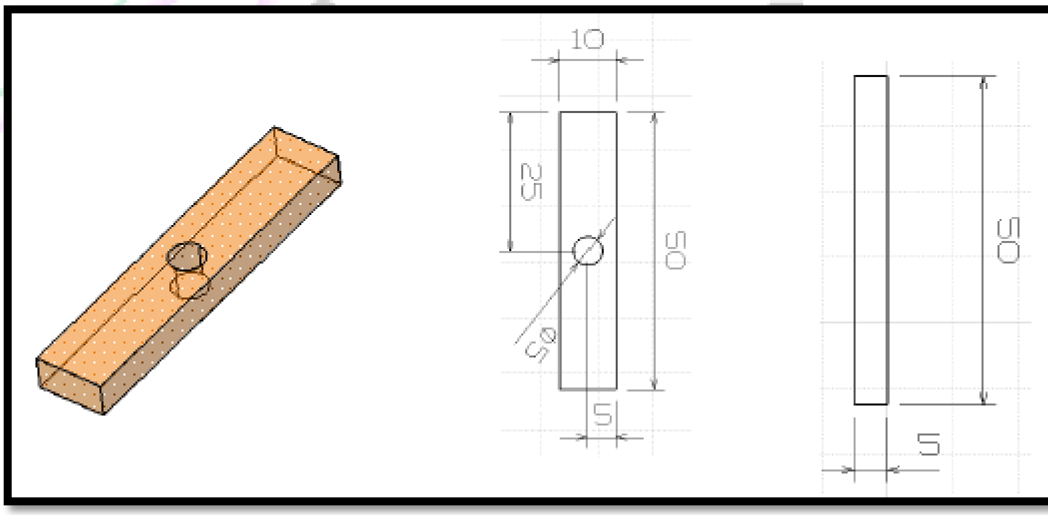




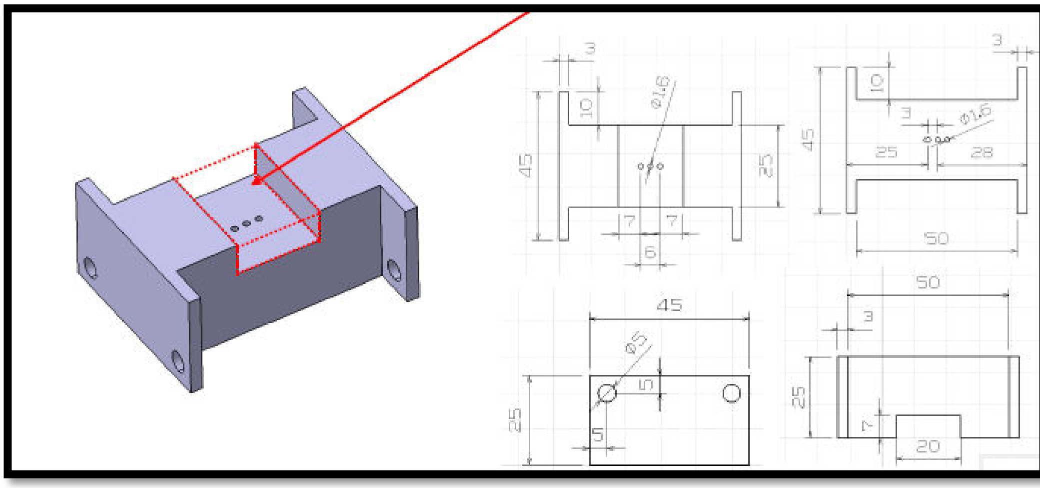
3. **Copper block:** It is a part in test section assembly which is connected with copper electrodes and PEEK block for supplying power to test specimen through its medium.



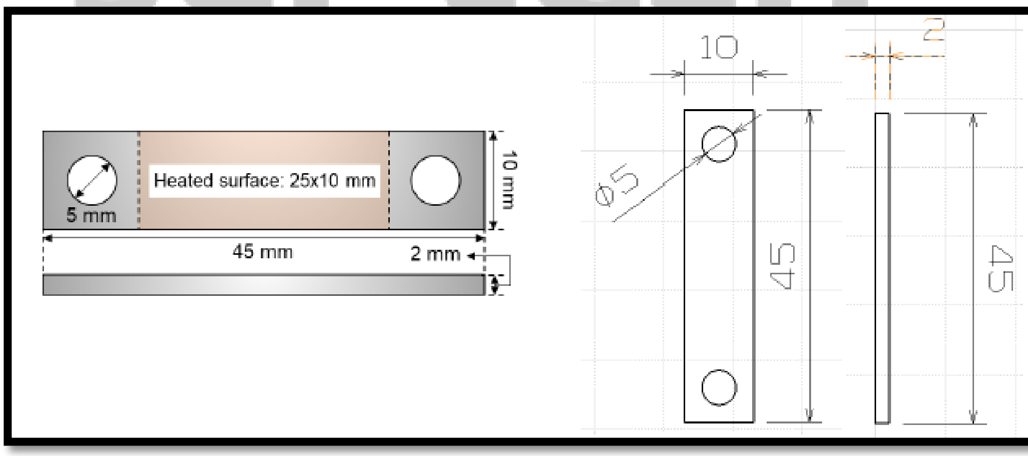
4. **Copper cover:** It's a part of test section assembly which is mounted on top of test specimen.



5. **PEEK block:** Polyether ether ketone in short form PEEK is a very useful insulating material for test section assembly. Epoxy is used in middle square hole.

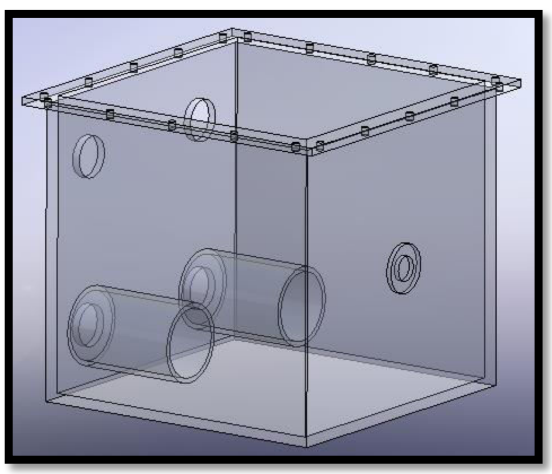


6. **Test specimen:** sample is of grade Stainless steel 304L as per standard specification with different surface roughness and non-treated or treated condition.



7. **SMPS DC power supply:** It is used for supplying power to test specimen, having rating of 10volts & 1200 Amps.

8. **Pool boiling chamber:** It's a made up of polycarbonate sheet of 8mm thickness having dimensions 300 x 300 mm.



9. **Water Heaters:** Heaters are of coil type made of stainless steel 304 grade with ratings of 500 watts and 1000 watts to heat the distilled water to perform experiment at saturation level

10. Data Acquisition Device: National instruments make module NI USB-6001 is used for data transfer in "**SCITECH DAQ SOFTWARE**".

5. Theory

Nucleate pool boiling is known to be a very effective mechanism of phase change heat transfer to achieve a much higher heat transfer coefficient than a single phase at a given temperature difference condition.

In the nucleate boiling regime, a number of bubbles are produced from the heat-generating surface, and the heat is rapidly transferred by their latent heat transport and local convection enhancement. However, the nucleate boiling regime is limited by a certain heat flux condition, the so-called critical heat flux (CHF).

The CHF is a maximum heat flux value to sustain the nucleate boiling regime. After the CHF point, the heated surface is covered with the vapor blanket, and the surrounding liquid is not able to touch the heated surface. In other words, the heat transfer mode changes from nucleate boiling to film boiling. In such a case, it leads to a dramatic decrease in the heat transfer performance and a sudden increase in the surface temperature, and consequently results in a failure of the heater surface.

Hence, the CHF enhancement is a key approach to maximize the efficiency and safety of a nuclear power plant. For a large safety margin and high performance of the nuclear reactor core, investigations on the enhancement of the CHF have been performed and reported extensively using nanofluids and surface modification.

Nanofluids, a dispersion of nanoparticles in water, have been reported to increase the CHF value. During the boiling, nanoparticles are deposited on the heater surface, which changes the surface conditions (e.g., morphology, roughness, and wettability). In other words, the surface change caused by the deposition of nanoparticles results in an increase in the CHF. The use of nanofluids could be an easy way to enhance the CHF, but it seems to have a limitation on nuclear core application, since there may be the undesired deposition on the components of nuclear power plant, and the effect of nanoparticles in nuclear reactor is not clear.

Critical heat flux (CHF) is an important criterion in nuclear reactor safety and the efficiency of boiling heat transfer. This parameter is known to be dependent of the surface roughness and the wettability of a material that is in contact with boiling fluid. Generally, CHF enhances with increasing surface roughness and wettability. However, the uncombined effect of each dependency is not yet well understood. One way to better understand this is to analyze the dynamic wetting behavior. Thus, this study reports the effect of dynamic wetting behavior on CHF using oxidized steel samples to modify roughness and wettability.

Direct Joule heating method was used. This method easily supplies steady state heat flux and exhibits fast thermal response. Applied heat flux was calculated using the Joule's heat flux equation. (Eq. (1))

$$q'' = \frac{Power}{heated\ area} = \frac{VI}{WL}$$

Here, V is the measured voltage drop across the test material, I is the measure current, W is the width of the heat transfer area, and L is the heated length. Uncertainty of the measured heat flux was estimated as 5.2% based on the propagation of error method.

6. Experiments

6.1 Experiment 01: To obtain critical heat flux of Non treated sample's

- **Conducting the experiment:**

1. Give single phase electric supply to trainer and switch on Mains.
2. Give three phase electric supply to DC power supply & switch on Mains.
3. Fill distilled water in pool boiling chamber up to heater levels.
4. Now load the specimens from the specimen's category on NS and OS inside test specimen block by opening top cover of pool boiling chamber.
5. Turn on heaters to heat the water up to its saturation temperature, it will take 50 to 60min for this process.
6. After reaching saturation temperature turn on DC power supply for power pass through the specimen.
7. Connect USB to PC/laptop and open SCITECH DAQ application for recording real time data.
8. From software pass initially 1volts to DC power supply and then gradually increase voltage and current simultaneously for recording no of observations time to time.
9. At time of opening DAQ software it will ask to store the data in PC/laptop so provide directions where to store data and click ok for starting the process.

10. When it will ask to store the data kept file as excel format for simplified view for that write the test name with (.xls) file format extension.
11. Now after supplying current and voltage specimen will reach at its critical point of heat transfer and it will break at maximum capacity which is its critical heat flux CHF can be calculate as per data and formulae described in theory part.
12. After completion of experiment let the specimen cool down at room temperature with distilled water and switch of mains, after that change the specimen by opening pool boiling chamber top cover and repeat the experiment with following steps from beginning.

- **Observation:** 1. Test specimen: Bare NS-320 or NS-600 or NS-800
  2. Dimension's: 25mm x 10mm x 2mm

Obs no.	Date	Time	T1 (C)	T2 (C)	T3 (C)	TC (C)	Voltage (V)	Current (Amp)
1								
2								
3								
4								
5								
6								

- **Nomenclature:**
  1. T1- Temperature sensor mounted on left side copper block (PT100 type)
  2. T2 – Temperature sensor mounted below PEEK block (PT100 type)
  3. T3–Temperature sensor mounted on right side copper block (PT100 type)
  4. TC – Temperature sensor mounted below test specimen (K type)

- **Calculations:**

Critical heat flux (CHF) = q" = $\frac{Power}{heated\ area} = \frac{VI}{WL}$ Kw/m^2

Heated area = W x L = width of specimen x length of specimen
= 25mm x 10mm
= 250mm^2

- **Graph:**

6.2 Experiment 02: To obtain critical heat flux of oxidized sample's

- **Conducting the experiment:**

13. Give single phase electric supply to trainer and switch on Mains.
14. Give three phase electric supply to DC power supply & switch on Mains.
15. Fill distilled water in pool boiling chamber up to heater levels.
16. Now load the specimens from the specimen's category on NS and OS inside test specimen block by opening top cover of pool boiling chamber.
17. Turn on heaters to heat the water up to its saturation temperature, it will take 50 to 60min for this process.
18. After reaching saturation temperature turn on DC power supply for power pass through the specimen.
19. Connect USB to PC/laptop and open SCITECH DAQ application for recording real time data.
20. From software pass initially 1volts to DC power supply and then gradually increase voltage and current simultaneously for recording no of observations time to time.
21. At time of opening DAQ software it will ask to store the data in PC/laptop so provide directions where to store data and click ok for starting the process.

22. When it will ask to store the data kept file as excel format for simplified view for that write the test name with (.xls) file format extension.
23. Now after supplying current and voltage specimen will reach at its critical point of heat transfer and it will break at maximum capacity which is its critical heat flux CHF can be calculate as per data and formulae described in theory part.
24. After completion of experiment let the specimen cool down at room temperature with distilled water and switch of mains, after that change the specimen by opening pool boiling chamber top cover and repeat the experiment with following steps from beginning.

- **Observation:**

1. Test specimen:

	300^{o} C	450^{o} C	600^{o} C
320 Sand paper	OS-SP320(300^{o}C)	OS-SP320(450^{o}C)	OS-SP320(600^{o}C)
600 Sand paper	OS-SP600(300^{o}C)	OS-SP600(450^{o}C)	OS-SP600(600^{o}C)
800 Sand paper	OS-SP800(300^{o}C)	OS-SP800(450^{o}C)	OS-SP800(600^{o}C)

2. Dimension’s: 25mm x 10mm x 2mm

Obs no.	Date	Time	T1 (C)	T2 (C)	T3 (C)	TC (C)	Voltage (V)	Current (Amp)
1								
2								
3								
4								
5								
6								

- **Nomenclature:**

5. T1- Temperature sensor mounted on left side copper block (PT100 type)
6. T2 – Temperature sensor mounted below PEEK block (PT100 type)
7. T3–Temperature sensor mounted on right side copper block (PT100 type)
8. TC – Temperature sensor mounted below test specimen (K type)

- **Calculations:**

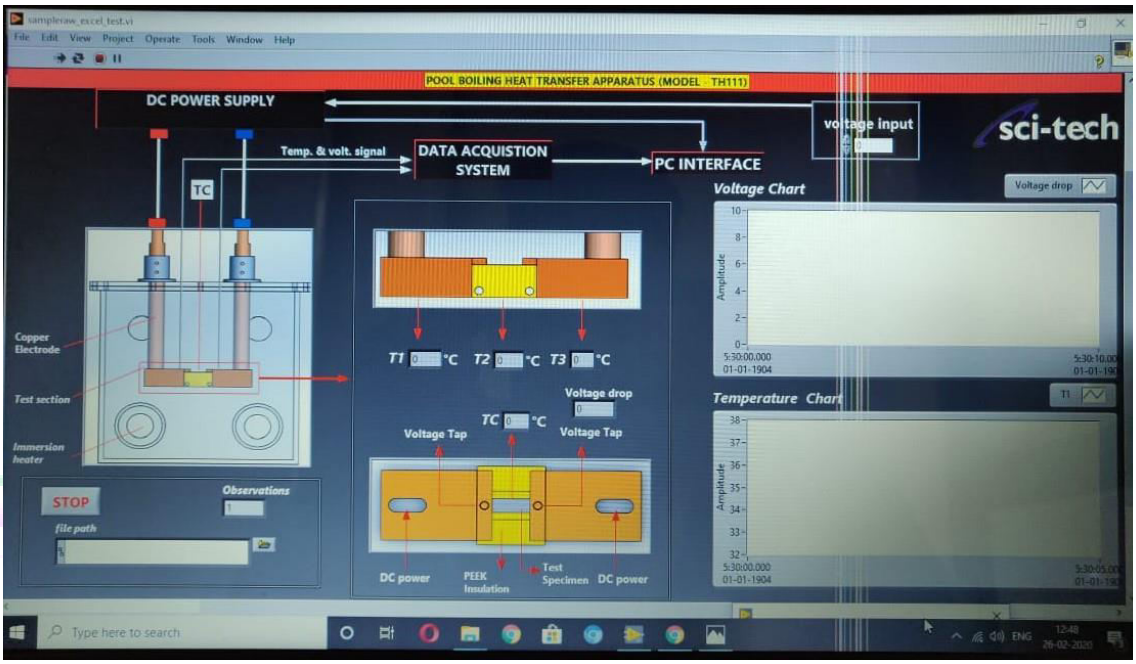
Critical heat flux (CHF) = q" = $\frac{Power}{heated\ area} = \frac{VI}{WL}$ Kw/m^2

Heated area = W x L = width of specimen x length of specimen
= 25mm x 10mm
= 250mm^2

- **Graph:**

6.3. Appendix: Sample cellulations, Results, graph and screenshots of DAQ software

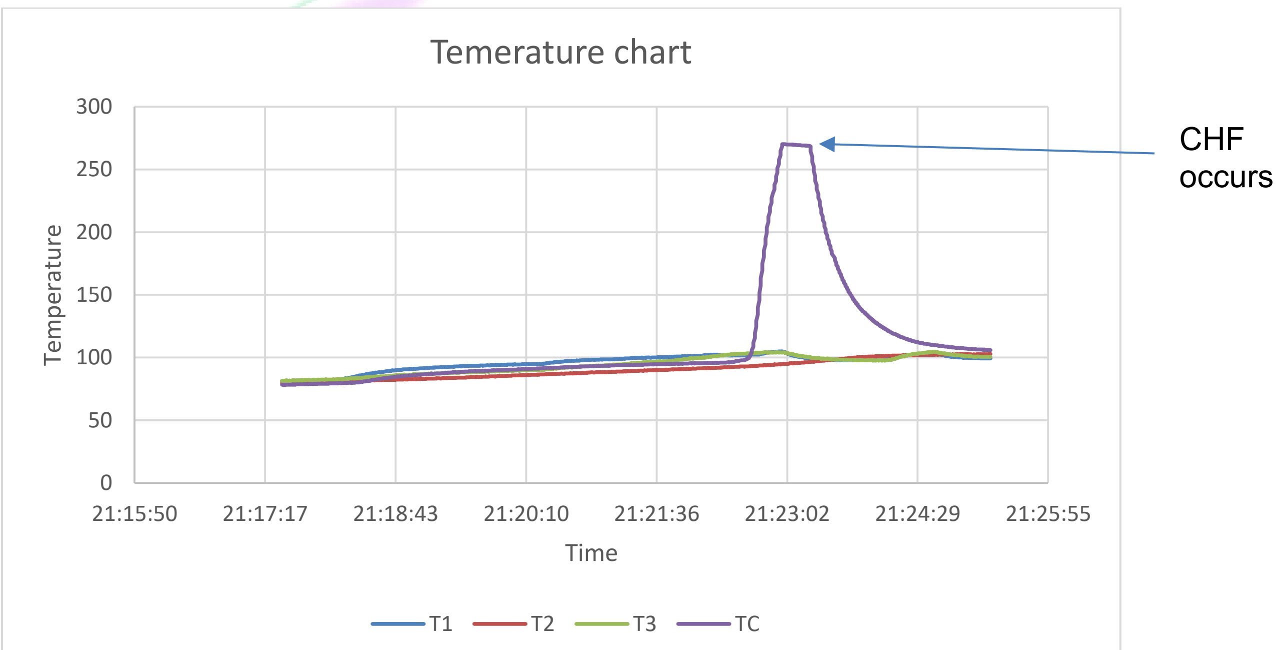
1. **Software screenshots:**



2. **Excel sheet screenshots:**

1	Date	Time	Observati	T1 (C)	T2 (C)	T3 (C)	TC (C)	Voltage (V)
2	28-02-2020	21:04:29	1	67.661	58.034	62.683	72.753	0.991
3	28-02-2020	21:04:30	2	67.661	57.966	62.548	72.753	1.004
4	28-02-2020	21:04:30	3	67.724	58.101	62.817	72.701	0.963
5	28-02-2020	21:04:31	4	67.661	57.966	62.952	72.857	0.953
6	28-02-2020	21:04:31	5	67.724	58.101	62.75	72.753	0.958
7	28-02-2020	21:04:32	6	67.661	58.101	62.548	72.857	0.976
8	28-02-2020	21:04:32	7	67.724	58.101	62.75	72.701	0.927
9	28-02-2020	21:04:33	8	67.85	58.303	62.75	72.857	0.953
10	28-02-2020	21:04:33	9	67.787	58.101	62.548	72.805	1.03
11	28-02-2020	21:04:34	10	67.85	58.169	63.087	72.753	0.995
12	28-02-2020	21:04:35	11	67.977	58.169	62.75	72.857	1.025
13	28-02-2020	21:04:35	12	67.913	58.236	63.02	72.909	0.972
14	28-02-2020	21:04:36	13	67.85	58.236	62.683	72.909	0.941
15	28-02-2020	21:04:36	14	67.913	58.169	62.885	72.805	0.985
16	28-02-2020	21:04:37	15	67.85	58.169	62.75	72.961	0.985
17	28-02-2020	21:04:37	16	67.913	58.169	63.087	73.013	0.957
18	28-02-2020	21:04:38	17	67.913	58.236	62.548	73.064	0.963
19	28-02-2020	21:04:38	18	68.04	58.303	63.02	73.064	0.927
20	28-02-2020	21:04:39	19	68.04	58.303	62.952	73.064	0.924
21	28-02-2020	21:04:39	20	68.103	58.303	63.087	72.909	0.986
22	28-02-2020	21:04:40	21	68.103	58.303	62.817	73.013	0.954
23	28-02-2020	21:04:40	22	68.04	58.371	62.817	73.013	1.055
24	28-02-2020	21:04:41	23	68.103	58.371	63.222	73.116	0.958
25	28-02-2020	21:04:41	24	68.04	58.303	62.817	73.168	1.003

3. Graphs:



4. Calculations:

As per data, sample data calculations for OS-SP320(600°C)

Obs no.	Date	Time	T1 (C)	T2 (C)	T3 (C)	TC (C)	Voltage (V)	Current (Amp)
1	28-02-2020	21:22:57	104.6	94.55	103.9	257.6	2.248	
2	28-02-2020	21:22:58	104.8	94.48	104.1	261..1	2.304	
3	28-02-2020	21:22:58	104.8	94.75	104.2	264.7	2.596	
4	28-02-2020	21:22:59	104.6	94.68	103.8	268.3	2.664	
5	28-02-2020	21:22:59	104.9	94.75	103.7	270.1	1.419	
6	28-02-2020	21:23:00	104.6	94.88	103.9	270.1	0.355	
7	28-02-2020	21:23:00	104.6	94.88	104.1	270.1	0.792	
8	28-02-2020	21:23:01	104.3	95.02	103.8	270.0	0.938	

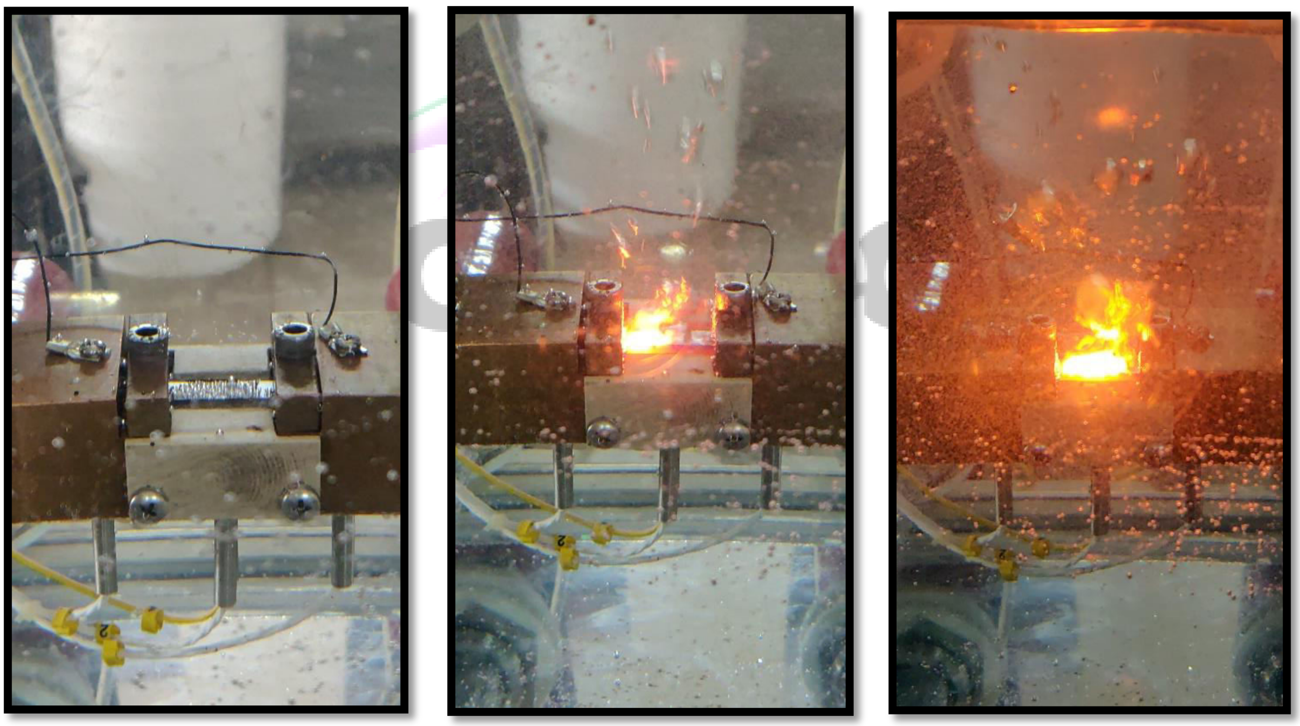
As per data captured in excel sheet some data is observed here as on data no 04 having maximum break temperature and voltage so we will calculate CHF at this point for specimen OS-SP320(600^{o})

Here,
Voltage (V) = 2.664
Current (A) =
Width of sample = 10mm = 0.01m
Length of specimen= 25mm = 0.025m

CHF = $\frac{VI}{WL} = \frac{2.664 \ x \ 250}{0.01 \ x \ 0.025}$ = 2664000 W/m^2 = 26664 Kw/m^2

So CHF critical heat flux of specimen OS-SP320(600^{o}C) is 2664 Kw/m^2

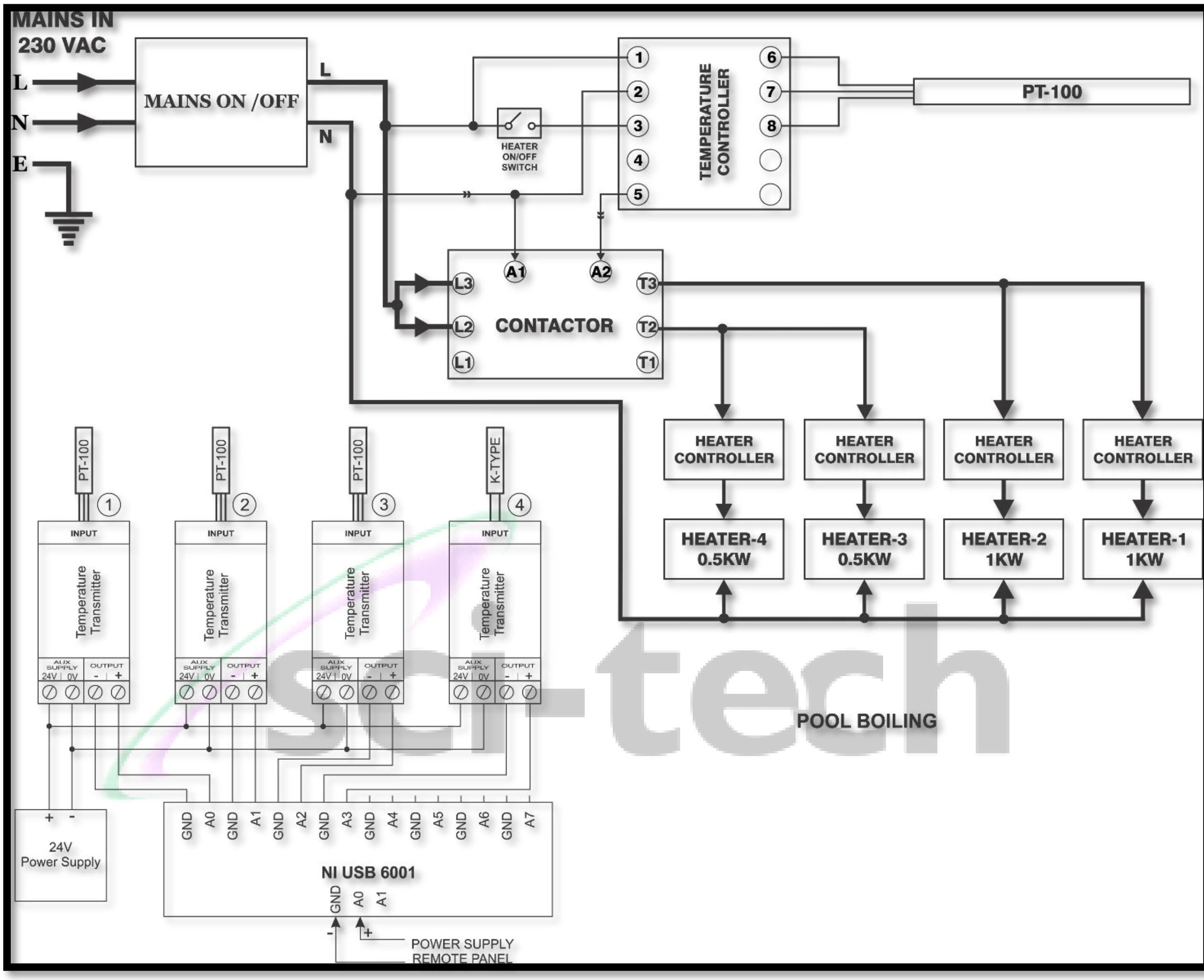
5. Specimen Experimental images:



a. Start of pool boiling b. CHF occurrence start c. CHF occurred

d. After Performing experiment at maximum CHF

7. Wiring Diagram



MAINS IN
230 VAC
L
N
E
MAINS ON /OFF
L
N
HEATER ON/OFF SWITCH
TEMPERATURE CONTROLLER
PT-100
A1
A2
L3
L2
L1
CONTACTOR
T3
T2
T1
HEATER CONTROLLER
HEATER CONTROLLER
HEATER CONTROLLER
HEATER CONTROLLER
HEATER-4 0.5KW
HEATER-3 0.5KW
HEATER-2 1KW
HEATER-1 1KW
PT-100
PT-100
PT-100
K-TYPE
INPUT
Temperature Transmitter
POOL BOILING
GND A0 GND A1 GND A2 GND A3 GND A4 GND A5 GND A6 GND A7
NI USB 6001
GND A0 A1
24V Power Supply
POWER SUPPLY
REMOTE PANEL

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