ASSESSING SMOKE AND HEAT RELEASE DURING COMBUSTION OF ELECTRIC CABLES USING CONE CALORIMETER

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POLYMERIC MATERIALS

Various types of power cables, data cables and fire survival cables for specific applications are used.

Polymeric materials are widely used in cable industries

- Availability in nature
- Physico - chemical properties
- Ease of manufacture and design

Cables ---- transportation of electric power

PVC, XLPE, Flame Retardant PVC, polyolefin based Low Smoke Zero Halogen (LSZH) --- insulating & sheathing

Factors influencing fire and smoke characteristics of cables

- Generic nature of materials and presence or absence of additives such as fire retardants
- Construction, size and laying of cables
- Presence or absence of the combustibles & heat sources
- Availability of air
- Movement of fire products with air
- Presence or absence of fire suppression / extinguishing agents

Electric cables - pathway for fire spread due to its insulating and sheathing materials

- Polymeric materials - medium of fuel

  ----- liberation of heat

  ----- smoke and toxic gases

  ----- fire spread
- fire behaviour of cable

  ---- construction & constituent materials

FIRE SAFETY EVALUATION TECHNIQUES

Sl. No.	Name of the Equipment	Test	Test Standard
1.	Critical oxygen Index apparatus	To determine the Oxygen index at ambient temp.	ASTM D 2863 IS 10810 (Part 59)
2.	Temperature Index apparatus	To determine the oxygen index at elevated temp.	IS 10810 (Part-64)
3.	Smoke Density test	To determine the Smoke Density Rating	ASTM D-2843
4.	Halogen Acid test apparatus	To determine the acid generation quantitatively	IEC 60754-1,60754-2 IS10810 Part 59
5.	3 Metre Cube simulating the actual situations	To determine the smoke density of Electric Cables	IEC 61034-2 IS10810 Part 63
6.	Fire resistant test	To check the circuit integrity of cable under electric stress as well as to flame	IEC 60331 BS 6387

FIRE SAFETY EVALUATION TECHNIQUES

Sl. No.	Name of the Equipment	Test	Test Standard
7.	Flammability test apparatus (bunched cables)	To check the behavior of flame propagation under full scale	IEC 60332 Part-3 IS 10810 (Part-62)
8.	Flammability Test for single wire cable	To check the representative or single sample of cable for its flame propagation	IEC 60332 Part-1 IS 10810 IS 10810 (Part-61)
9.	Sweedish Chimney test	To check the propagation of flame when the entire cross sectional area is exposed to liquid fuel	NCD 1409 / NES 713
10.	Toxicity Index test	To find the release of toxic gases from polymeric materials	

HEAT RELEASE MEASUREMENT

Heat release is an important parameter characterizes the total available energy (HRR) of burning cables factor for quantifying the growth and spread of fire

- Predicts the real-scale burning behavior of materials
- It quantifies fire size, rate of fire growth
- The release of smoke and toxic gases
- HRR --- key indicator of fire
- MARHE, the maximum average rate of heat emission is another parameter --- assesses the fire behavior of materials.

CONE CALORIMETER

To determine the unwanted fire by determining the various parameters like

1. Rate of heat release
2. Rate of heat release per unit area
3. Mass loss rates
4. Time to ignition
5. Effective heat of combustion
6. Critical ignition flux

A view of cone calorimeter

Principle of measurement

The instrument is based on the principle of oxygen consumption calorimetry, where the net heat of combustion of any organic material is directly related to the amount of oxygen required for combustion.

Approximately 13.1 MJ of heat are released per kilogram of oxygen consumed.

The test specimens can be irradiated at heat fluxes from 10 – 100 kW/m^2 using a truncated conical heater element to simulate a range of fire intensities

Definitions

- Time to Ignition, TTI (s) – determined visually and taken to be the period required for the entire surface of the sample to burn w ith a sustained luminous flame.

- Peak Rate of Heat Release, Peak RHR (kW/m^2) – taken as the peak value of the heat release rate vs. time curve, and considered to be the variable that best expresses the maximum intensity of a fire, indicating the rate and extent of fire spread.Average

- Rate of Heat Release, Av.RHR (3 min), (kW/m^2) – taken as the average value of the heat release rate for the period from ignition to 180 seconds, this parameter is thought to correlate with the heat release in a room burn situation where not all of the material is ignited at the same time.

Definitions

- Fire Performance Index, FPI ($m^2.s/kW$) – defined as the ratio of TTI to Peak RHR. It has been suggested that this parameter relates to the time to flashover (or the time available for escape) in a full-scale fire situation.

- Total Heat Released, THR (MJ/m^2) – total heat evolved by the sample over the entire test period, calculated by integrating the curve of heat release rate vs. time.

- Mass loss (g) – specimen mass loss during the entire test period, also expressed in terms of percentage loss based on initial specimen mass.

- Specific Extinction Area, SEA (m^2/kg) – a measure of smoke obscuration averaged over the entire test period.

Definitions

- Smoke Parameter, SP (MW/kg) – defined as the product of SEA and Peak HRR. This parameter is indicative of the amount of smoke generated in a full-scale fire situation.

- Total Smoke Released, TSR (non-dimensional) – total smoke evolved by the sample over the entire test period, calculated by integrating the curve of rate of smoke release vs. time.

- Carbon Monoxide Yield, CO (kg/kg) – yield of CO averaged over the entire test period, based on mass of sample consumed.

- Carbon Dioxide Yield, CO_2 (kg/kg) – yield of CO_2 averaged over the entire test period, based on mass of sample consumed.

In addition

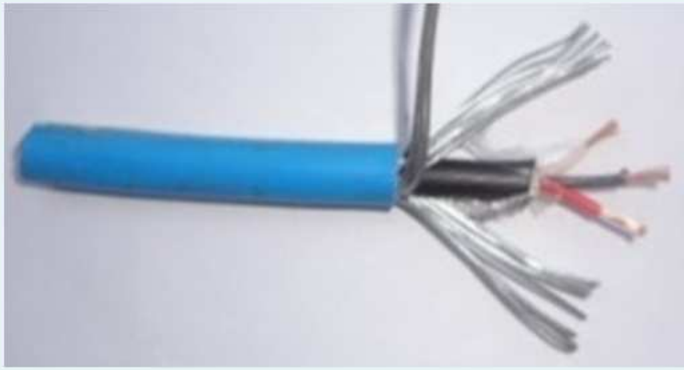
- Smoke release rates
- Toxic gas measurements
- Parameters like Fire growth rate (FIGRA)

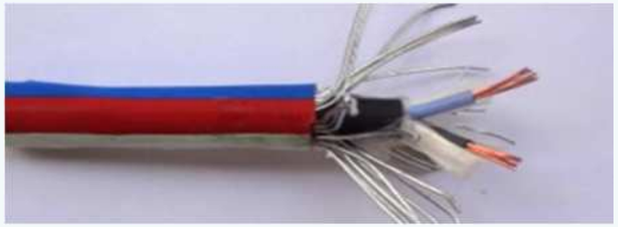
- FIGRA = peak HRR (30 secs)
  time to peak
- Smoke growth rate (SMOGRA**)**

The Cone Calorimeter

ASTM 1354 / ISO 5660

Table 1 Description of the cables tested

	1 x 3 x 1.0 sq mm, 300 V XLPE insulated, PVC inner sheathed, PVC outer sheathed and galvanized round steel armoured
	1 x 2 x 2.5 sq mm, 500 V, silicon insulated, Polyolefin based LSZH sheathed and unarmoured Instrumentation cable
	8 pair, 0.5 sq.mm multi stranded copper, insulated with polyolefin material and each pair is shielded with aluminum and polypropylene film. Further the eight pairs are covered with polypropylene film and overall sheathed with FRLS PVC

	3 core, copper multi-stranded 2.5 sq mm, PVC insulated cable PVC inner sheathed, HR PVC outer sheathed and galvanized round steel armoured Instrumentation cable
	4 pair with multi stranded copper of size 1.5 sq mm insulated with silicon. All the four cores shielded with aluminum foil and covered with outer sheath based on EVA.
	2 core 1.5 sq mm, copper multi-stranded conductor insulated with EVA, screened with aluminum foil and EVA sheath, 500 V Instrumentation cable
	2 pair with core size of 1.5 sq.mm multi stranded copper polyolefin insulated. Each pair shielded with aluminum and polypropylene film. Further the two pairs are wrapped with polypropylene film and overall sheathed with FRLS PVC

A View of Sample Holder with Instrumentation Cables

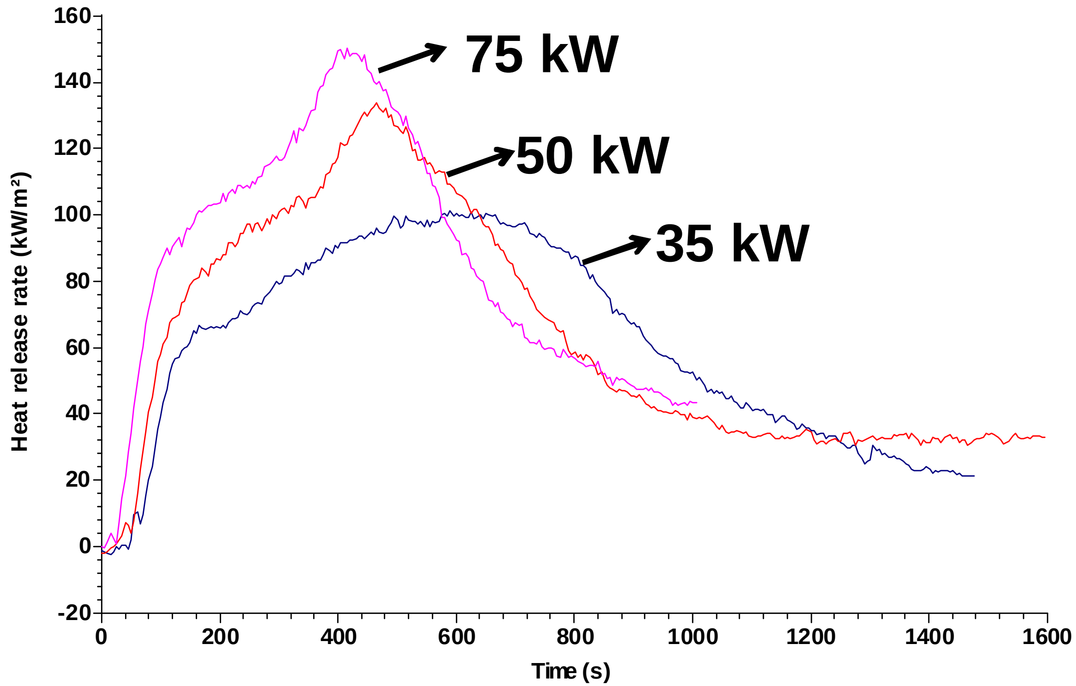
Specimen preparation

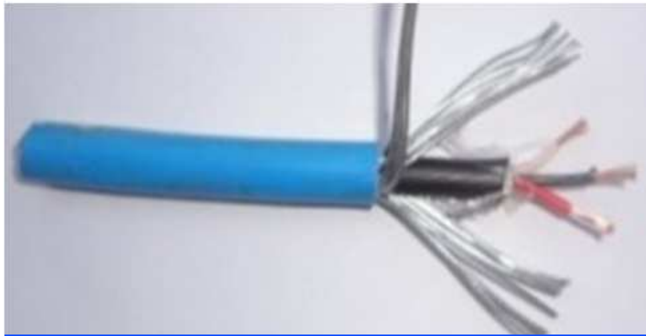
- Outer sheath of power cables were wrapped in a single layer of aluminum foil (0.1 mm thick) with shiny side toward the specimen covering the sides, bottom and the top surface exposed to thermal irradiance
- Instrumentation / communication cables, cable length each of 100 mm were cut and positioned side by side, in an aluminum foil tray of 0.1 mm thick.
- The tray with specimens was placed on top of a bed of low density refractory fibre blanket in the sample holder.
- The number of cables for each test was arrived by dividing 100 by diameter of the cable.

Results

The cable was tested at 35, 50 and 75 kW/m^2 heat flux. At each flux level the time to ignition, Heat release rate (HRR) peak, time to peak & MAHRE was measured.

Heat Release rate

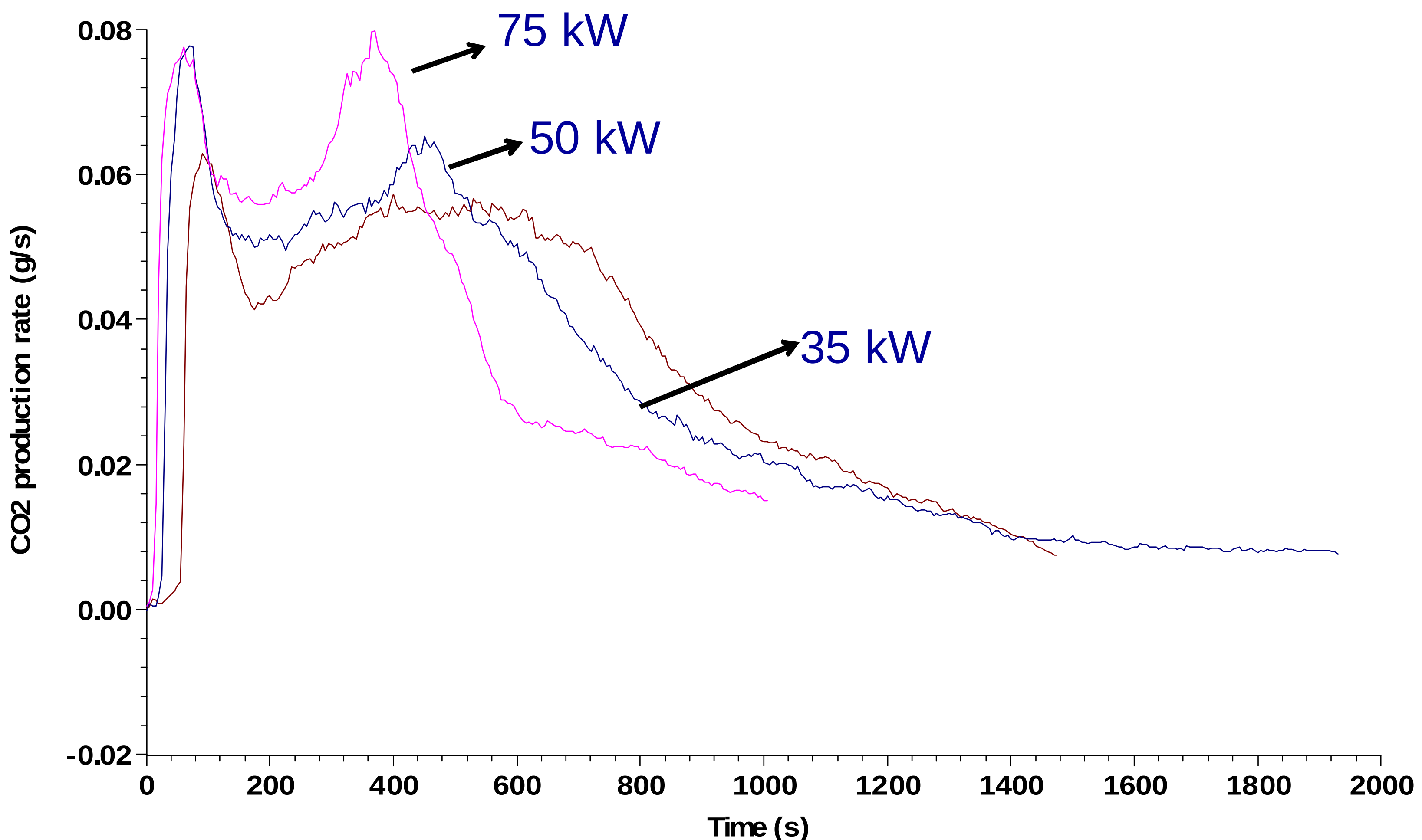




1 x 3 x 1.0 sq mm, 300 V XLPE insulated, PVC inner sheathed, PVC outer sheathed and galvanized round steel armoured

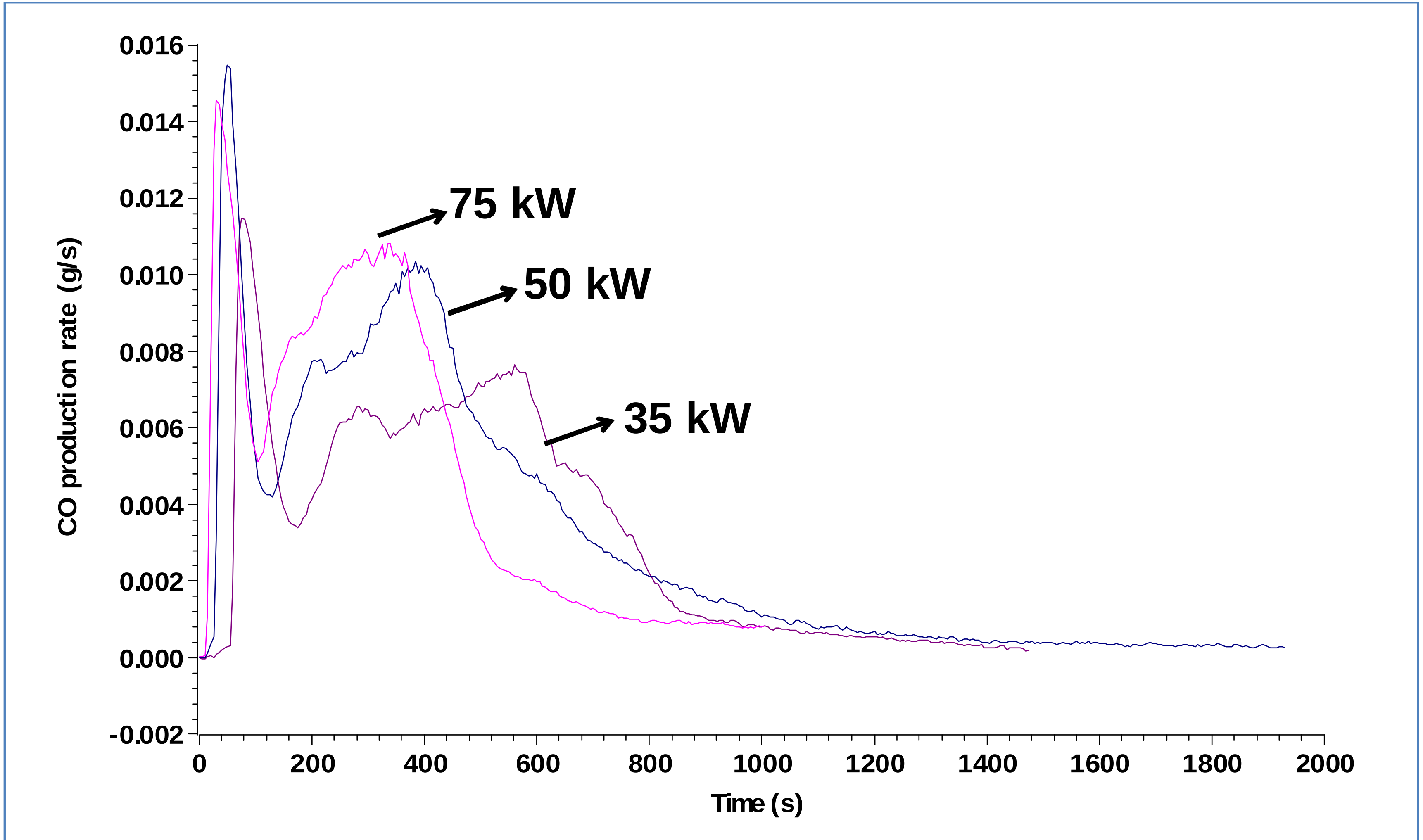
Flux (kW/m^2)	$t_{(ig)}$ (secs)	HRR (peak) (kW/m^2)	t_{peak}	MAHRE
35	54	100.99	590	76.40
50	22	133.68	465	90.77
75	11	149.97	415	105.29

Carbon di-oxide Rate



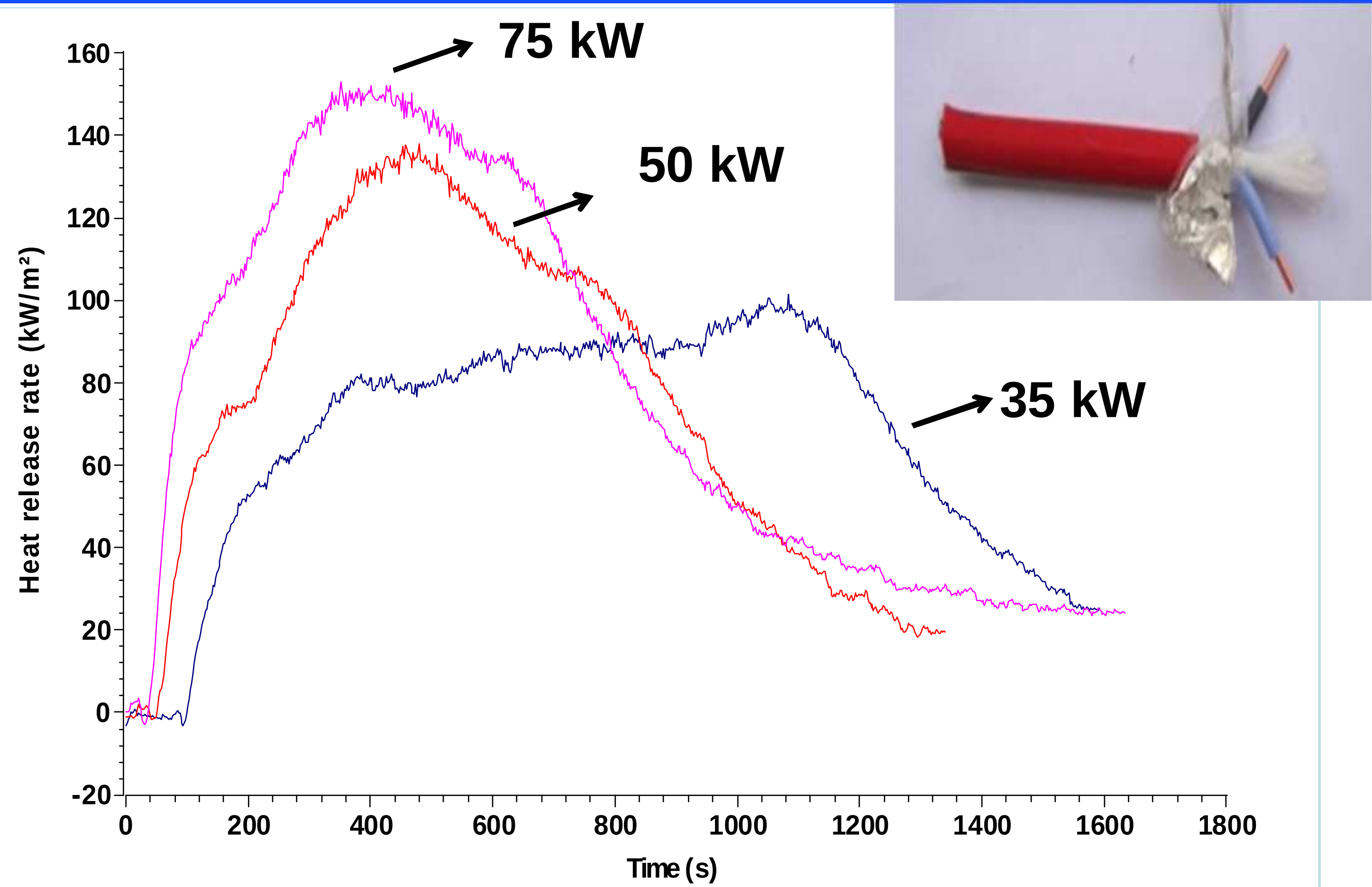
1 x 3 x 1.0 sq mm, 300 V XLPE insulated, PVC inner sheathed, PVC outer sheathed and galvanized round steel armoured

Carbon Monoxide Rate



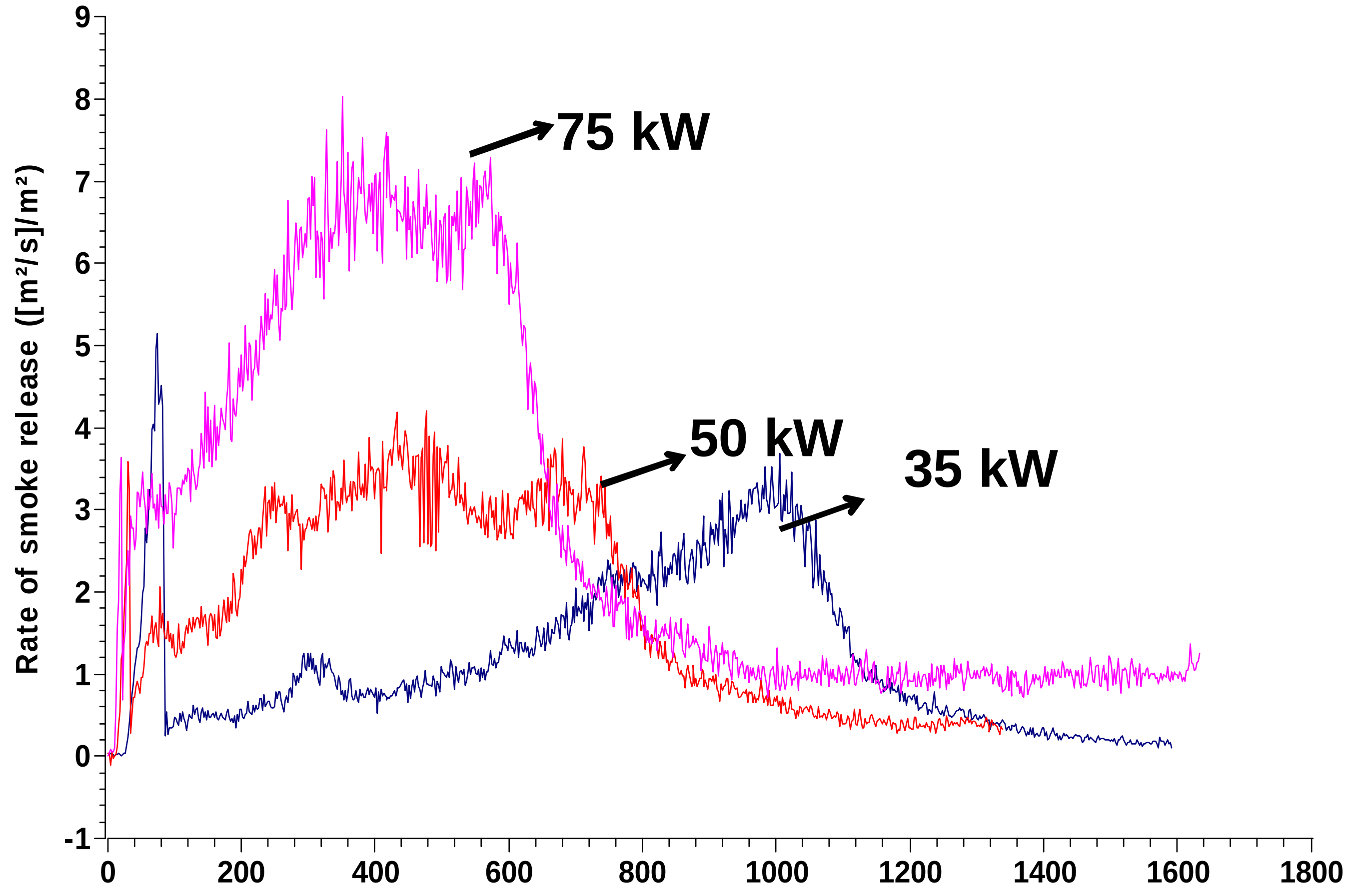
1 x 3 x 1.0 sq mm, 300 V XLPE insulated, PVC inner sheathed, PVC outer sheathed and galvanized round steel armoured

CABLE 2 *Heat Release rate*



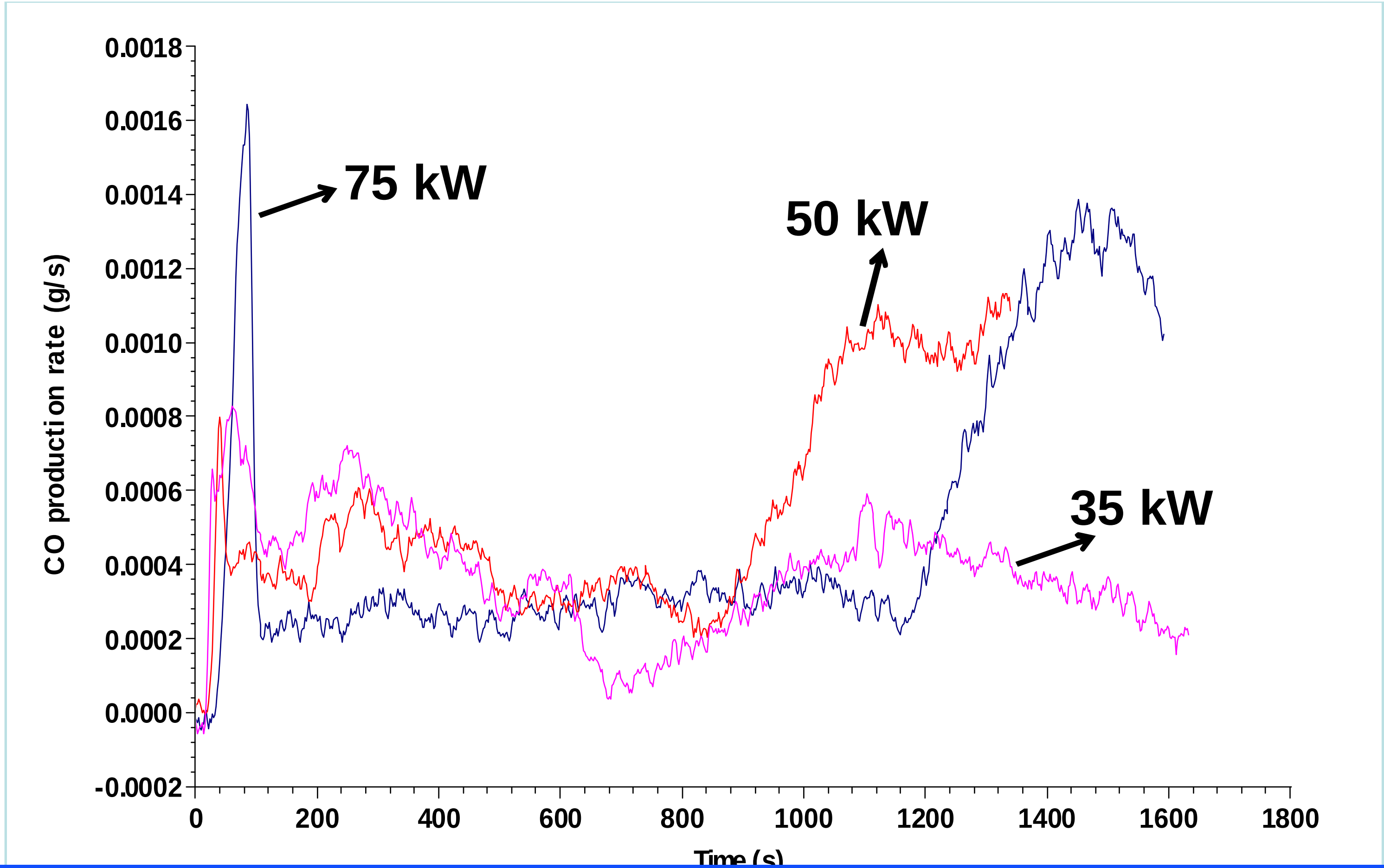
1 x 2 x 2.5 sq mm, 500 V, silicon insulated, Polyolefin based LSZH sheathed and unarmoured Instrumentation cable

Smoke release Rate



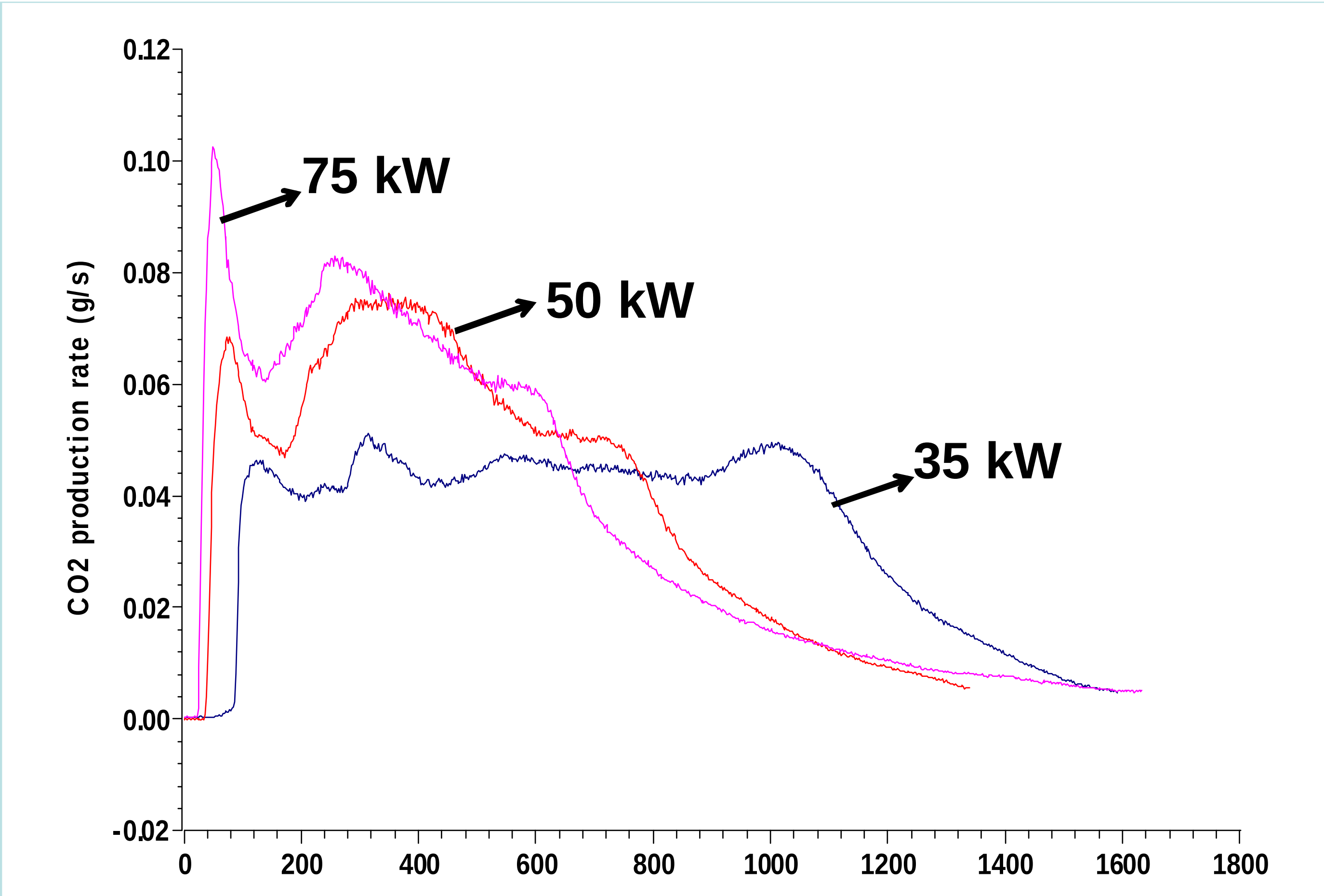
1 x 2 x 2.5 sq mm, 500 V, silicon insulated, Polyolefin based LSZH sheathed and unarmoured Instrumentation cable

Carbon Monoxide Rate



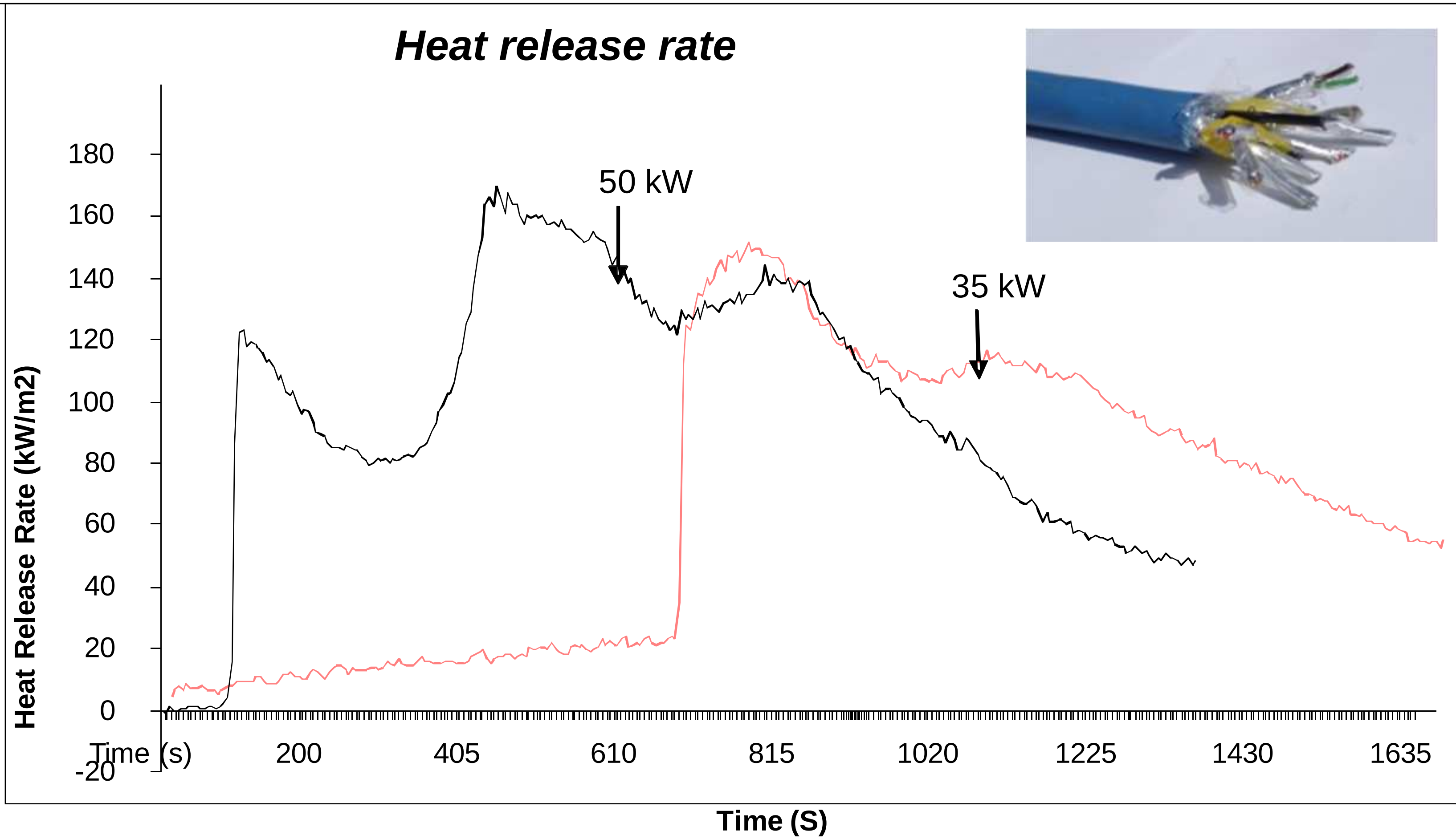
1 x 2 x 2.5 sq mm, 500 V, silicon insulated, Polyolefin based LSZH sheathed and unarmoured Instrumentation cable

Carbon di-oxide Rate



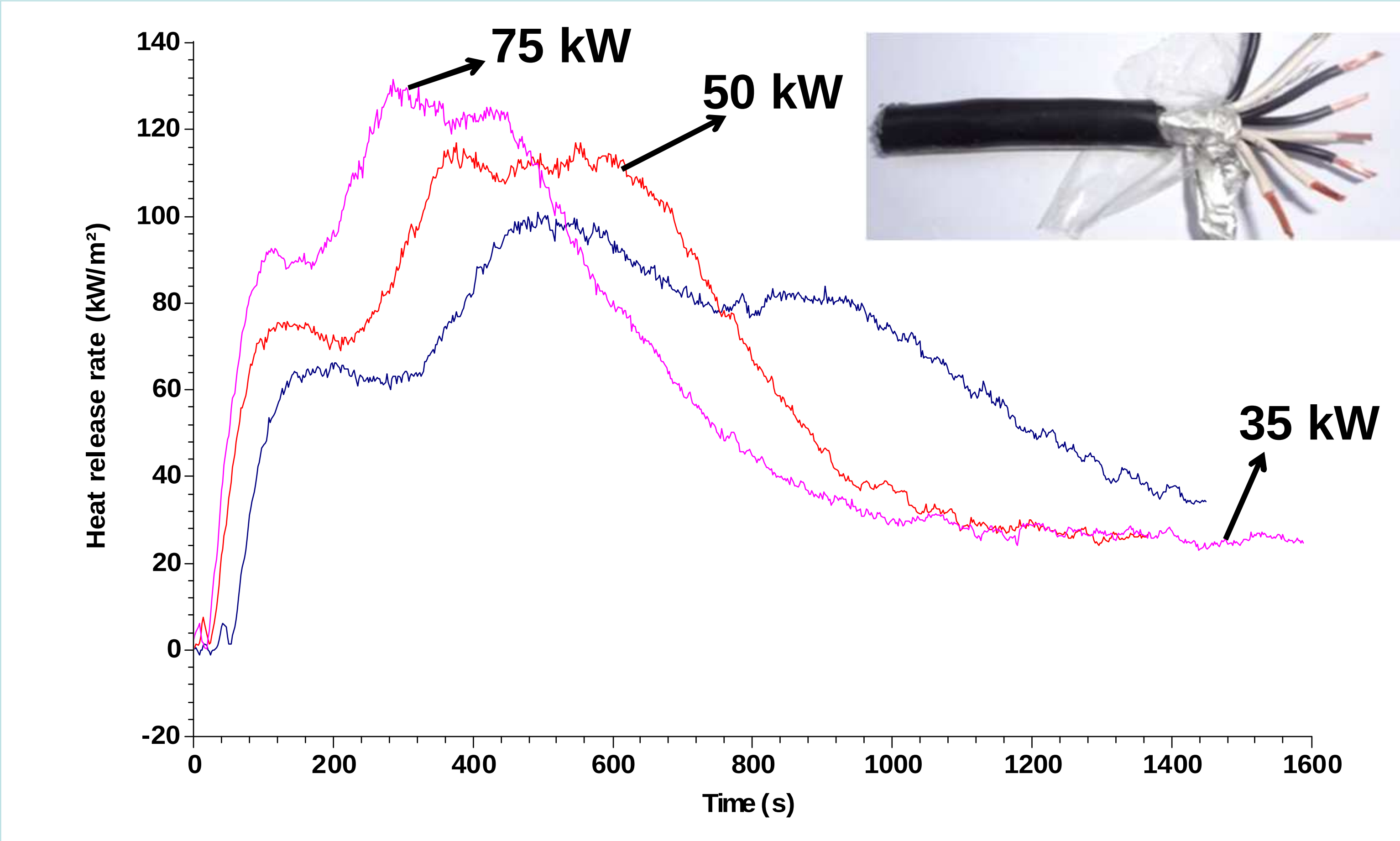
1 x 2 x 2.5 sq mm, 500 V, silicon insulated, Polyolefin based LSZH sheathed and unarmoured Instrumentation cable

CABLE 3



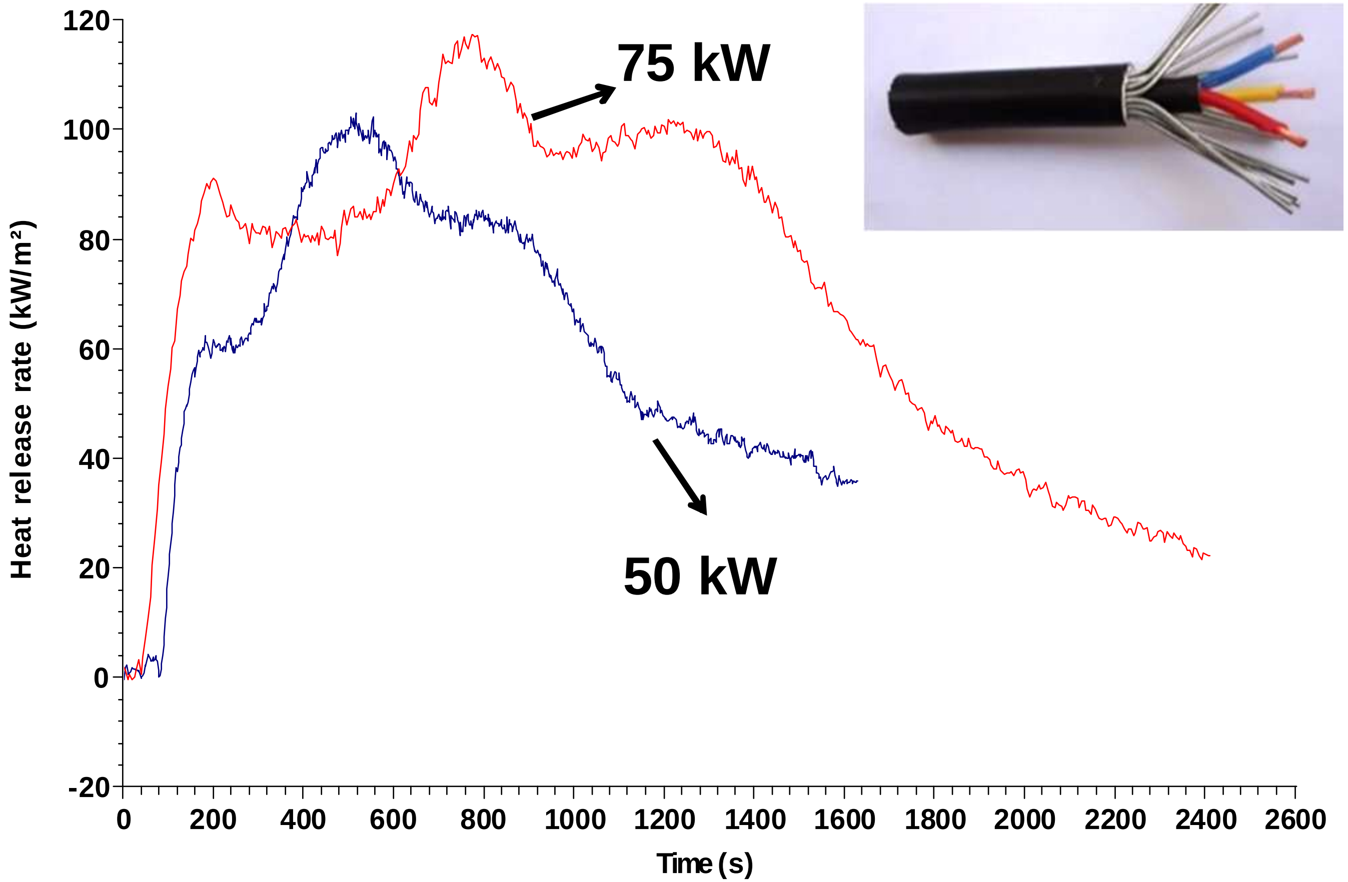
8 pair, 0.5 sq.mm multi stranded insulated with polyolefin material Further the eight pairs are covered with polypropylene film and overall sheathed with FRLS PVC

CABLE 4



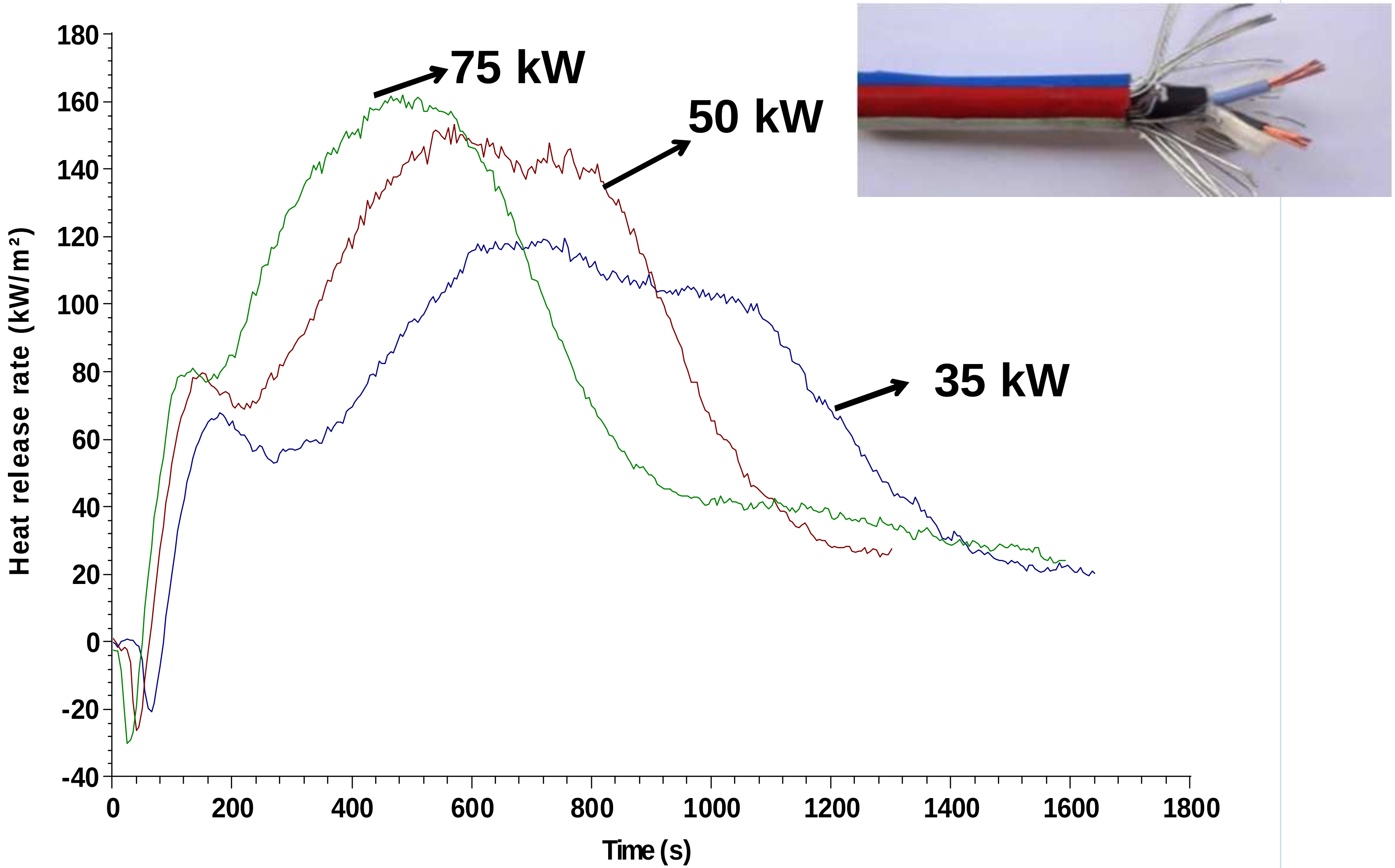
4 pair with multi stranded copper of size 1.5 sq mm insulated with silicon. All the four cores shielded with aluminum foil and covered with outer sheath based on EVA

CABLE 5



3 core, copper multi-stranded 2.5 sq mm, **PVC** insulated cable PVC inner sheathed, **HR PVC** outer sheathed and galvanized round steel armoured Instrumentation cable

CABLE 6



2 core 1.5 sq mm, copper multi-stranded conductor insulated with EVA, screened with aluminum foil and EVA sheath, 500 V Instrumentation cable

Table 3. Description of Power cable sheath Samples

Sheath sample	Cable description
PVC	PVC sheath 3 x 240 sq mm, XLPE insulated, 19/33 kV PVC sheathed cable
FRLS PVC	1 x 24 mm^2, 19/33 kV, XLPE Cable with FRLS PVC sheath
HFFR	1 X 400 SQ. MM, 33 kV XLPE cable with HFFR sheath
MDPE	3 X 185 SQ .MM 8.7 / 15 kV, XLPE cable with MDPE sheath.
HR PVC	12 pair 0.95 sq.mm, 300 / 500 V, HR PVC insulated and HR PVC sheathed cable
Polyolefin LSZH	1 x 400 sq.mm, XLPE 6 /10 kV LSZH inner and outer sheathed cable
FR PVC	Moulded FR PVC Insulation of 1 x 4.0 Sq mm, FR PVC insulated 1.1 kV Cable

A View of Cables Tested

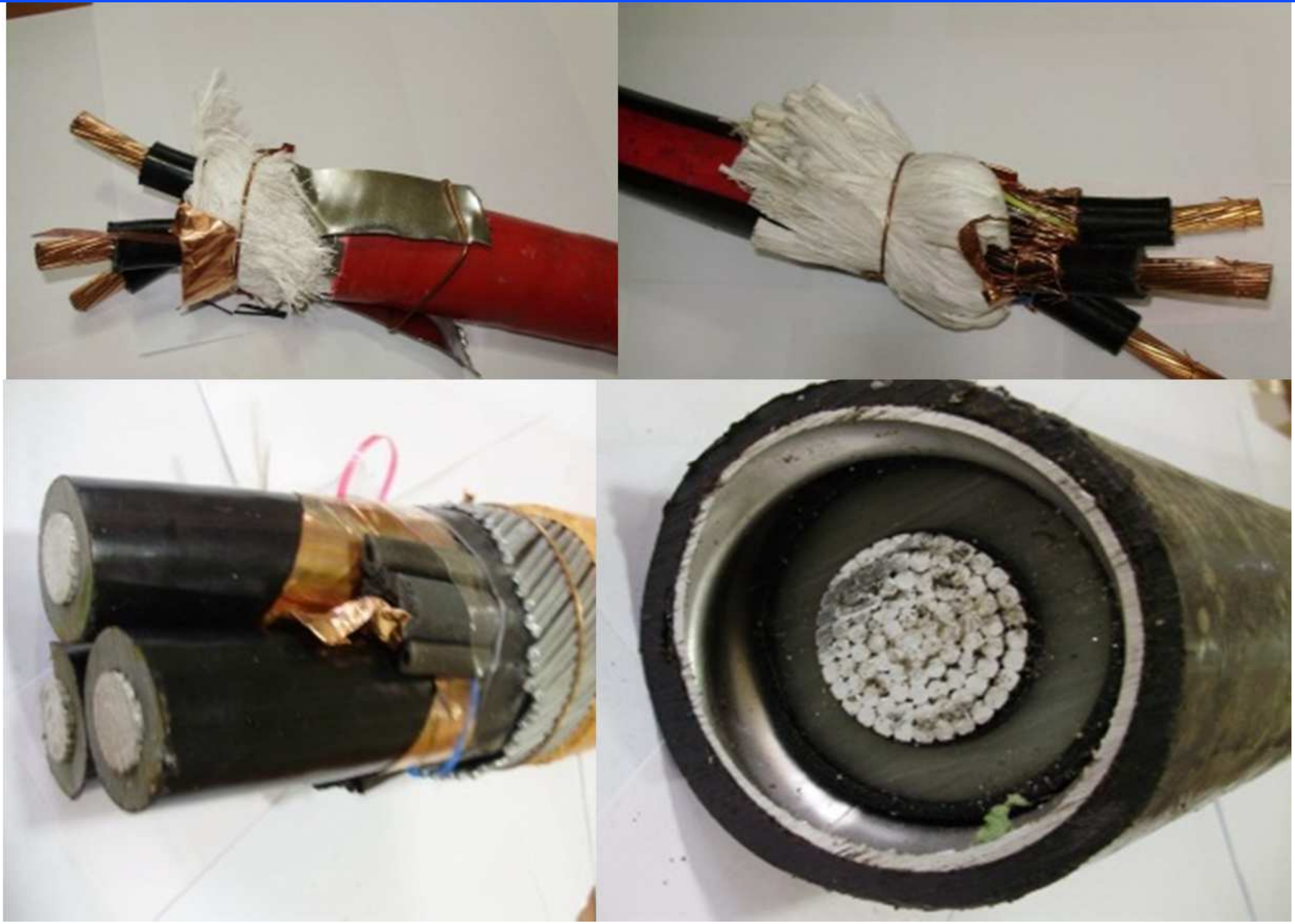
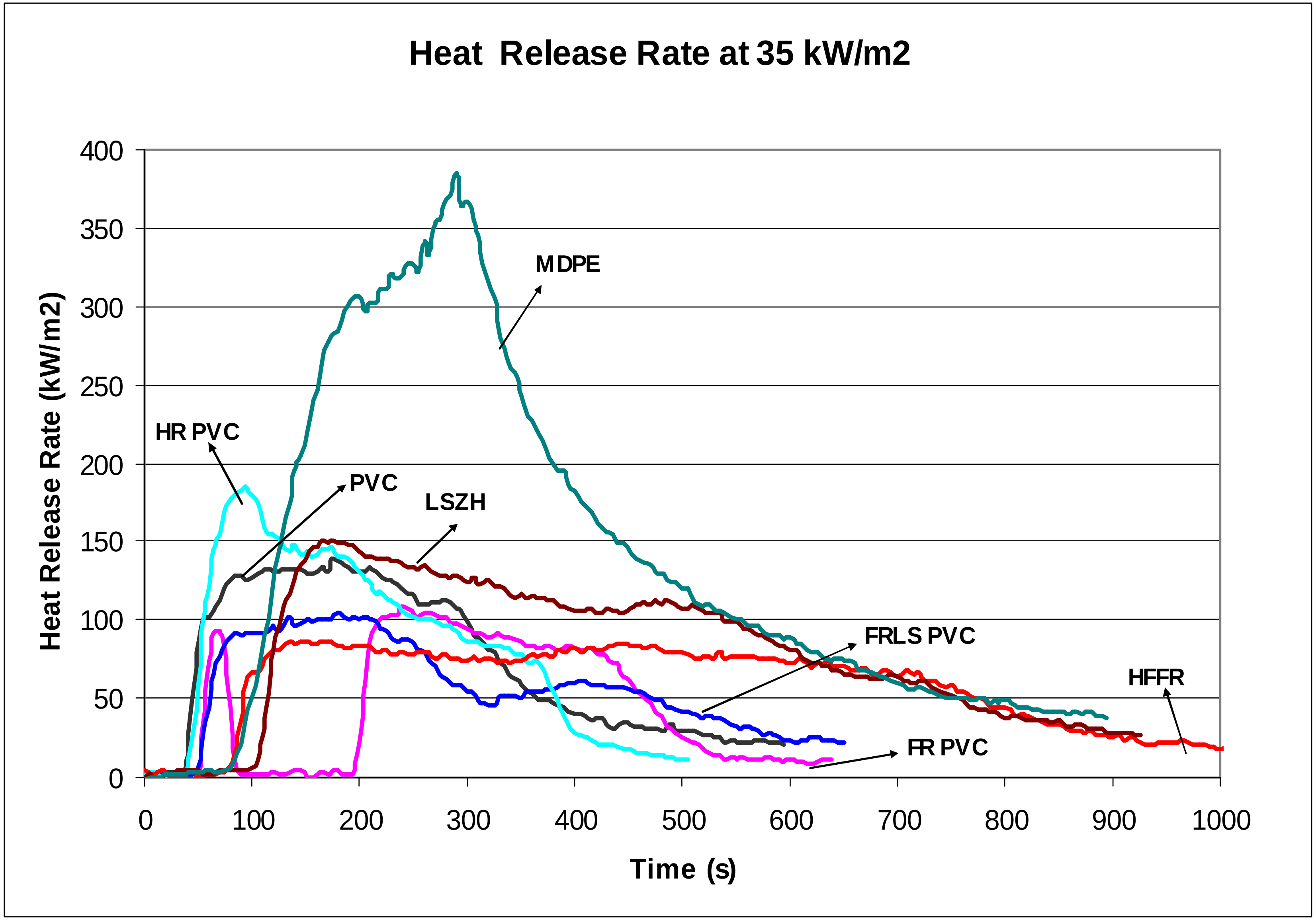


Table 4 Cone results of Power cable sheathing materials evaluated at 50 kW/m^2

		PVC	MDPE	FR PVC	HR PVC	FRLS PVC	HFFR	LSZH
1	Mass Loss	29.2	32.5	39.7	17.9	31.4	26.9	23.1
2	Ignition Time (Secs)	17	39	36	26	23	46	53
3	Peak HRR (kW/m^2)	165.8	604.5	124.6	243.2	112.1	136.1	185.3
4	Total HR (MJ/m^2)	41.5	112.9	28.6	47.4	37.7	62.1	63.2
5	Total Smoke(m^2)	20.7	13.7	26.9	4.2	10.8	4.1	5.3
6	MAHRE	126.5	280.7	63.3	153.7	87.4	96.1	112.1
7	Flame out Time (Secs)	575	660	582	478	561	711	678
8	Specific Extinction Area(m2/kg)	705.8	420.6	677.0	237.7	341.8	151.5	228.5
9	Total Smoke Release (m2/m2)	2350.6	1564	3187.5	489.2	1226.1	473.7	596.5

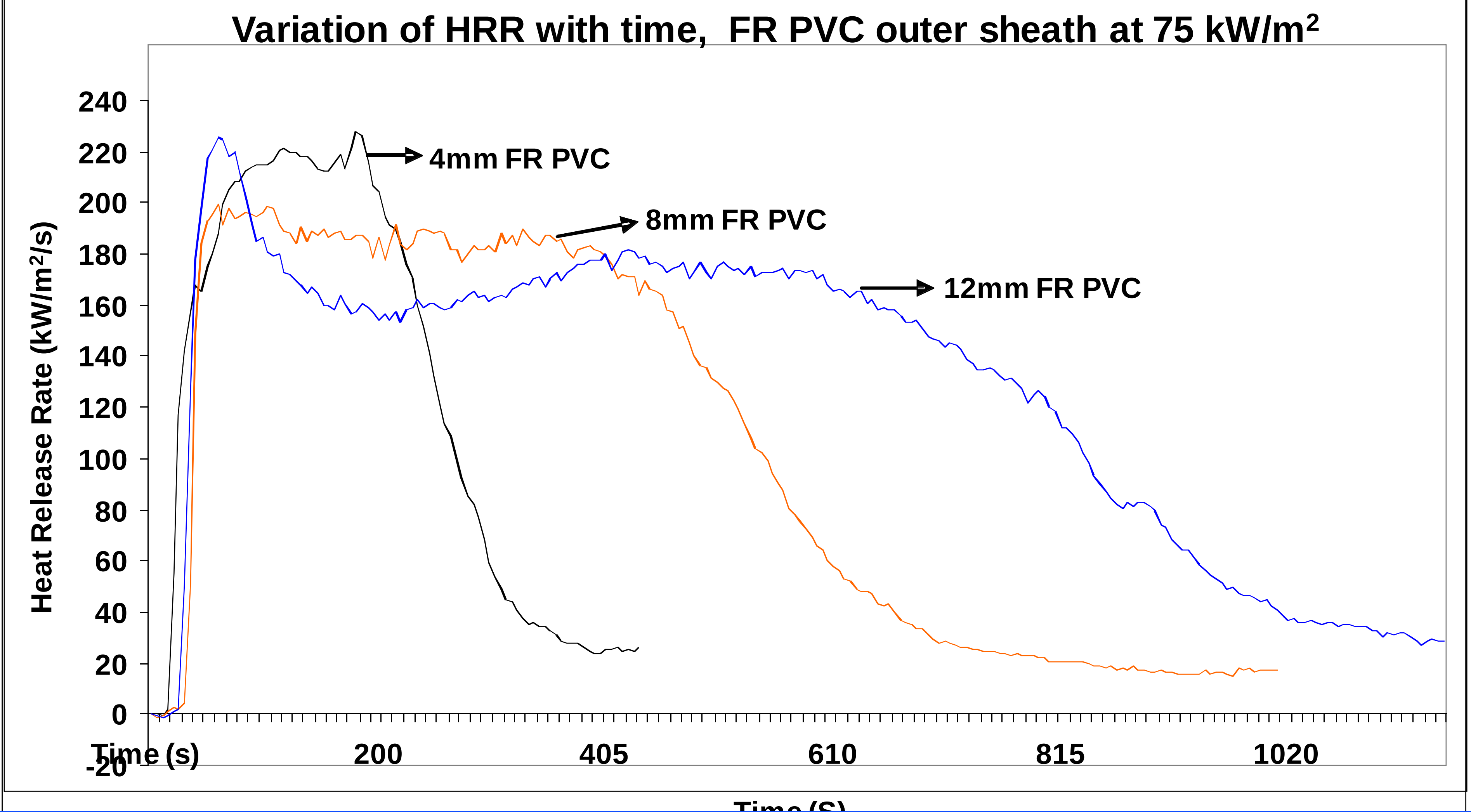
Observations

- Time to ignition is much shorter for samples tested at 50 kW/m^2 compared to samples evaluated at 35 kW/m^2 thermal flux
- Halogen Free Flame Retardant and LSZH materials have higher time to ignition signifying they are more heat resistant compared to PVC, FR PVC & others.
- The mass loss rate are more or less the same for both the thermal fluxes of 35 kW/m^2 and 50 kW/m^2
- It is also observed that peak HRR increases with increase in thermal flux and is highest for MDPE material compared to others.
- During tests on FR PVC sample it was observed that the sample was burning intermittently and multiple HRR peaks are observed.



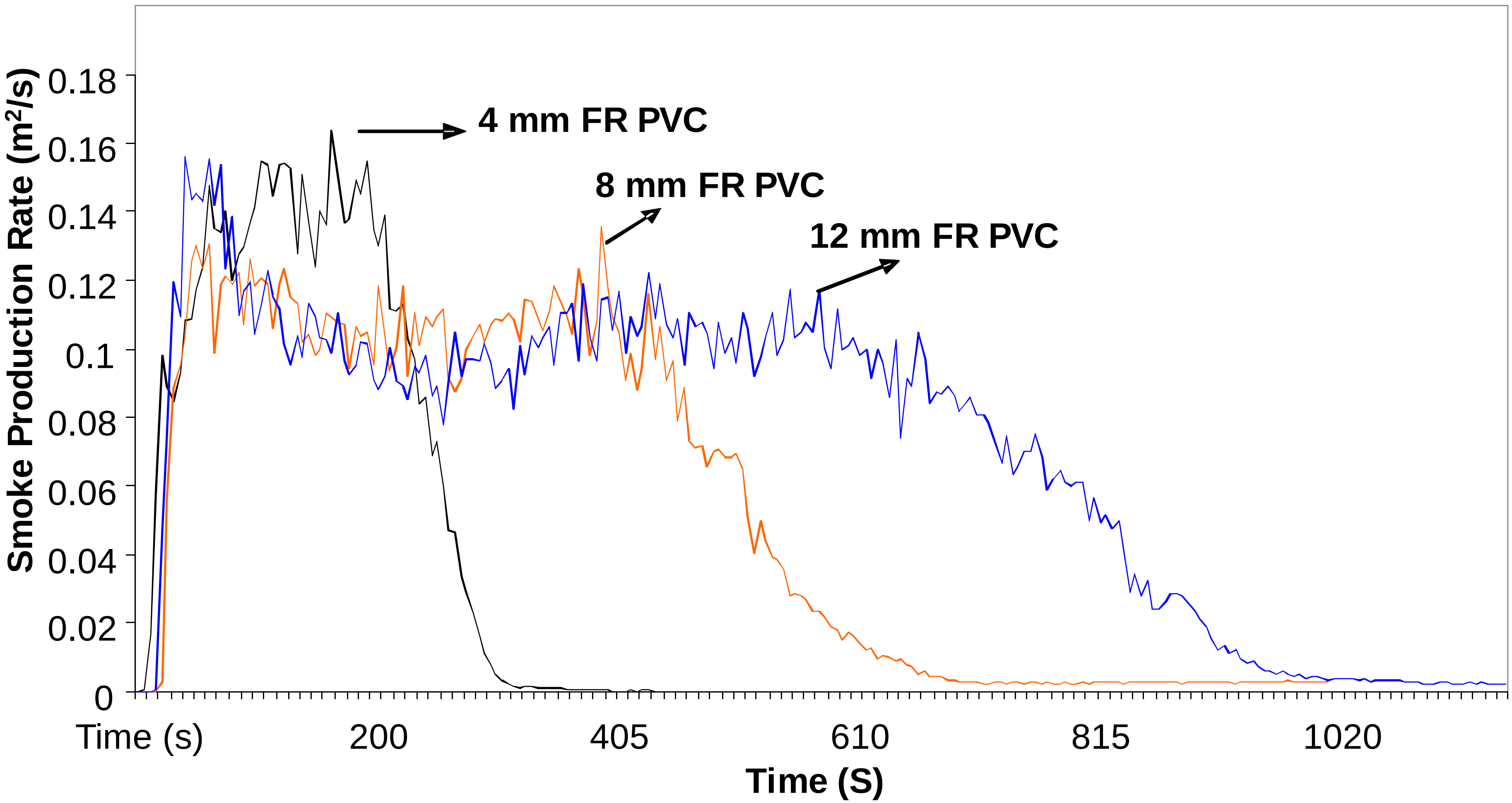
Heat Release Rate at 35 kW/m2
Heat Release Rate (kW/m2)
Time (s)
0
50
100
150
200
250
300
350
400
0
100
200
300
400
500
600
700
800
900
1000
MDPE
HR PVC
PVC
LSZH
FRLS PVC
HFFR
FR PVC

Heat Release Rate ($kW/m^2/s$)



The burning time and smoke production ---proportional to the thickness of the sample, as the quantity of combustible material increased

Smoke Production Rate (m^2/s)



Variation of Smoke production rate with time, FRPVC outer sheath at 75 kW/m^2

Observations

- The fire behavior of various sheath materials showed that the time to peak (HRR) is in the increasing order for the materials PVC, FR PVC, HDPE and ZHFR.
- The time to ignition of PVC and FR PVC shows that the fire retardation is very effective at both heat flux of 35 and 50 kW/m^2 heat intensities.
- CO_2 / CO ratios are high for Non FRLS compared to FRLS materials
- MAHRE values of all the materials have increased with the increase of heat flux.
- The order highest to lowest of peak value MAHRE is MDPE, HR PVC, PVC, LSZH, HFFR, FRLS PVC and FR PVC

CONCLUSIONS

Cone calorimeter measurements provide key parameters which enable to ascertain the fire behavior of material under different thermal fluxes.

Ignition times are much longer for FRLS cables compared to non FRLS cables.

FRLS cables have shown better results in terms of HRR, MAHRE and Smoke.

CO_2/CO ratios are also high for Non FRLS compared to FRLS cables.

The burning cables and materials can propagate flames from one area to another or they can add to the amount of fuel available for combustion with liberation of smoke and toxic gases

Thank you for your attention