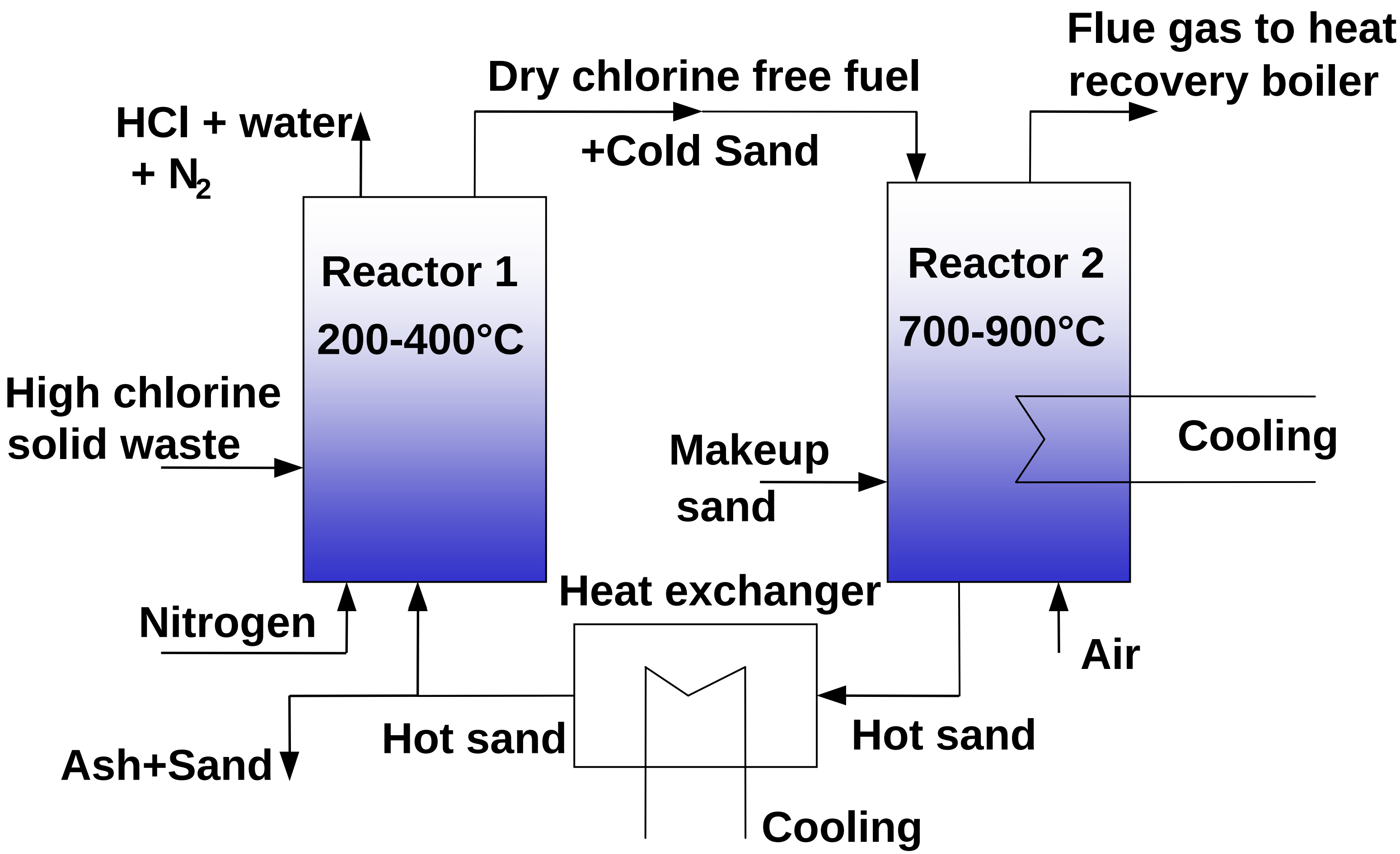
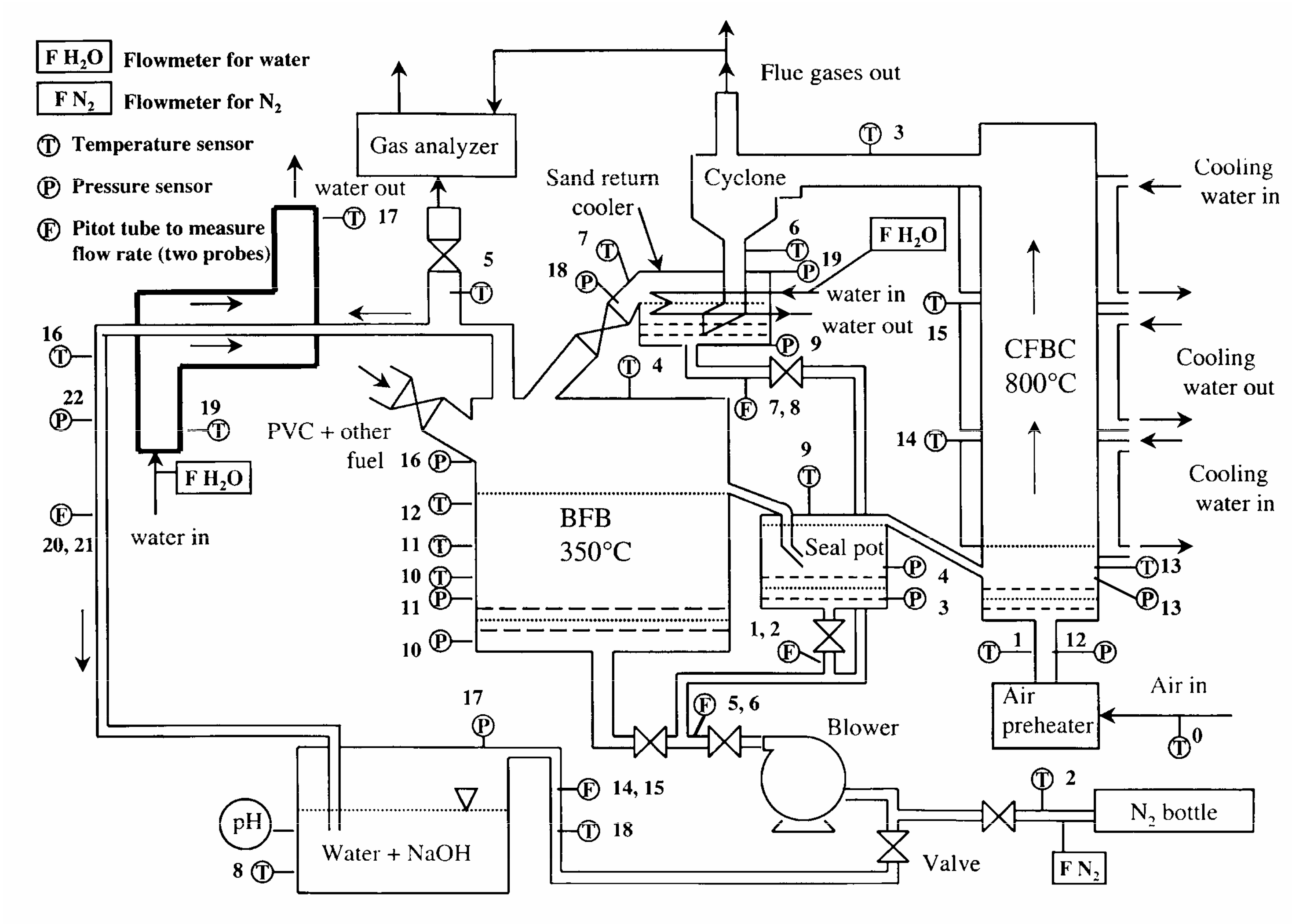
A Two-Stage Fluidized Bed Combustion Process for High PVC Solid Waste with HCl Recovery

Loay Saeed & Ron Zevenhoven
Helsinki University of Technology
Energy Engineering & Environmental Protection Laboratory
PO Box 4400, FIN-02015 Espoo Finland

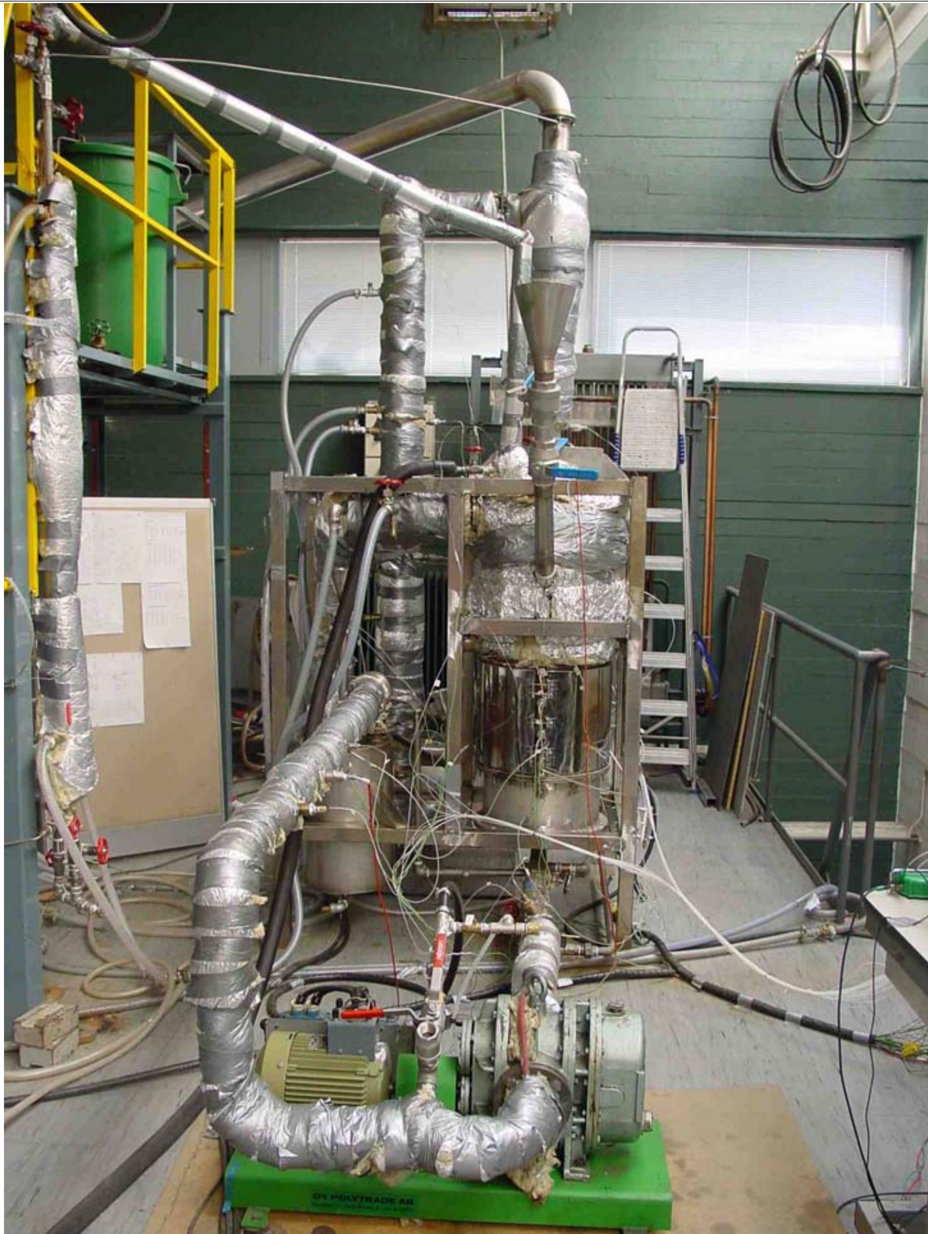
Simplified process diagram



Test facility scheme with measurement points



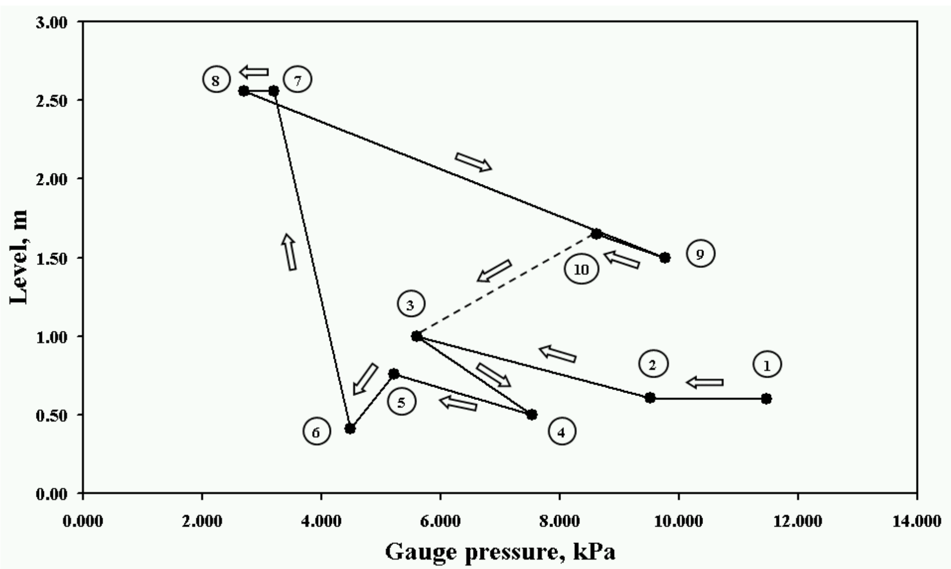
Front view of the two-stage combustion test facility

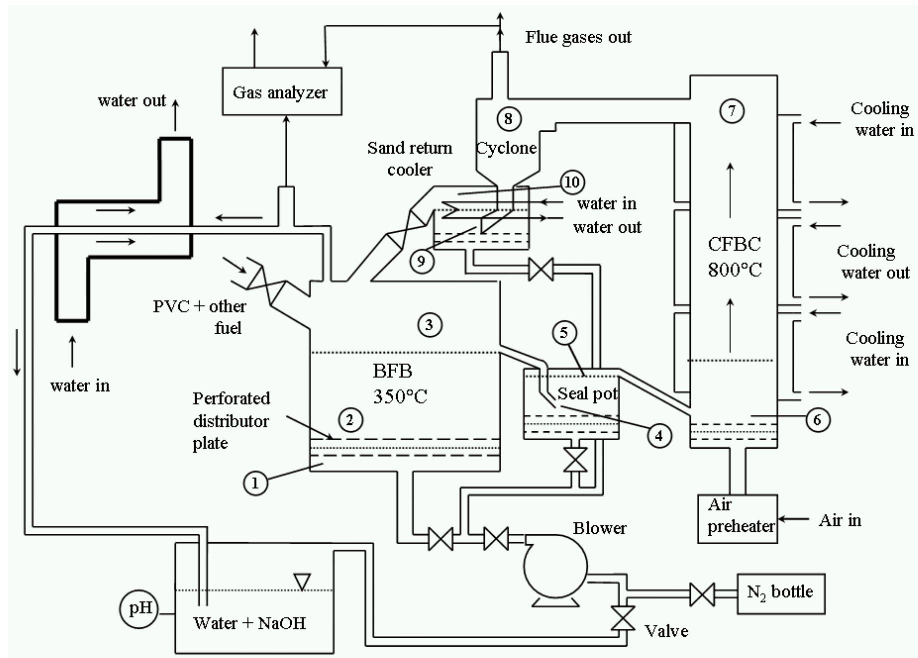


Design parameters for the two fluidized bed in the test facility

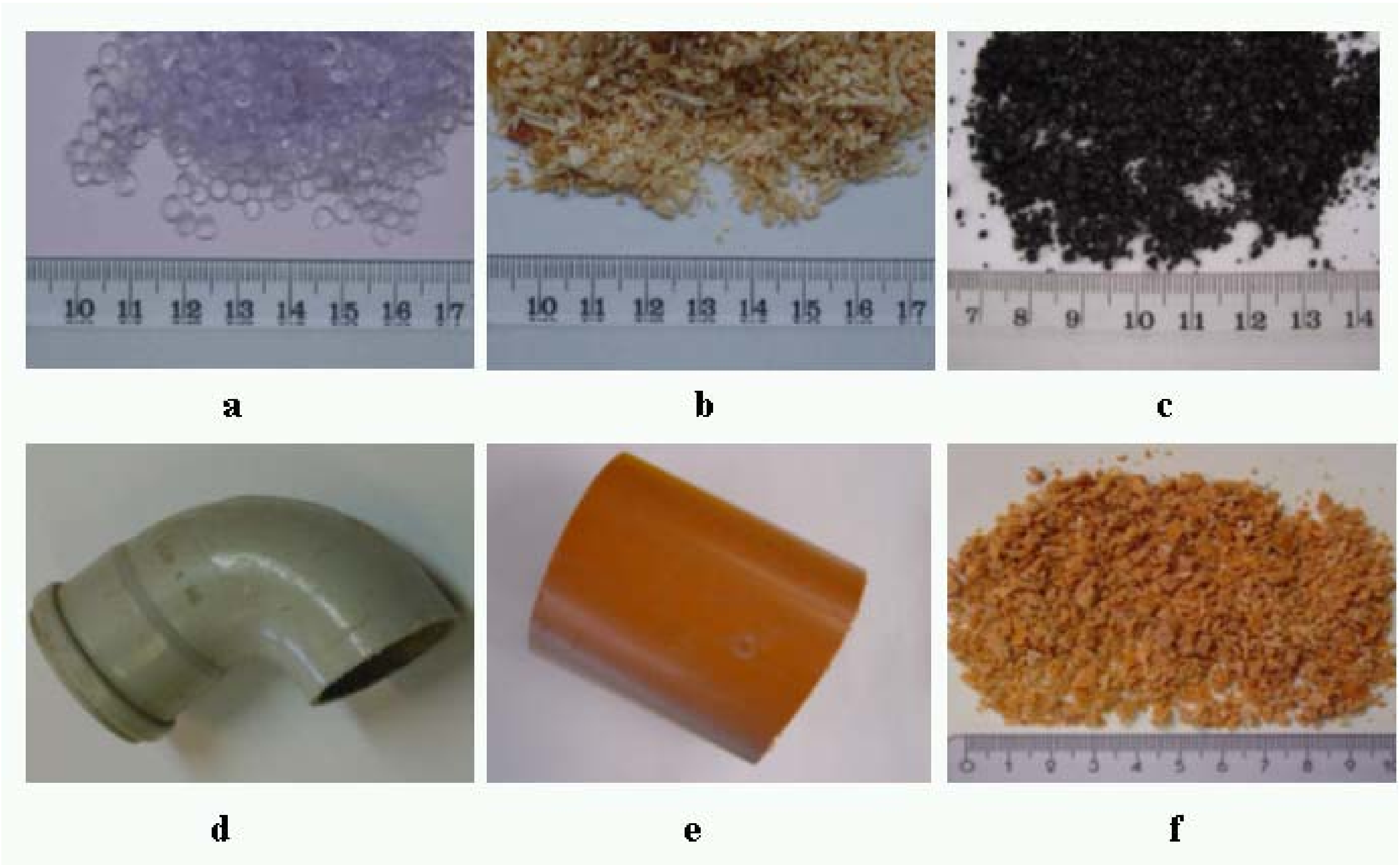
Parameter	BFB reactor	CFB combustor
Temperature, (°C)	200-400	< 900
Circular diameter, d_i (m)	0.4	0.11
Height, H_r (m)	0.8	2.3
Residence time of fuel, t (s)	1800	1-2
Fluidizing gas	Nitrogen	Air
Superficial gas velocity, U_o (m/s)	0.36 (at 350°C)	5 – 7 (at 800°C)
Minimum fluidization velocity, U_{mf} (m/s)	0.04 (at 350°C)	0.03 (at 800°C)
Particles terminal settling velocity of, U_t (m/s)	2.6 (at 350°C)	1.8 (at 800°C)
Gas flow, (liter/s STP)	~ 20	12 ~ 17
Expected product gas composition, (%-vol)	95 N_2, 1 H_2O 4 HCl	71 N_2, 12 H_2O, 15 CO_2, 1 O_2 , ~20 ppm HCl

Pressure distribution of two-stage combustion test facility





Fuel types used in the facility tests, a: bottle grade PVC, b: wood Finnish pine, c: Polish coal, d: light grey sewage PVC pipe (old), e: orange sewage PVC pipe (new) and orange sewage PVC pipe after grinding.

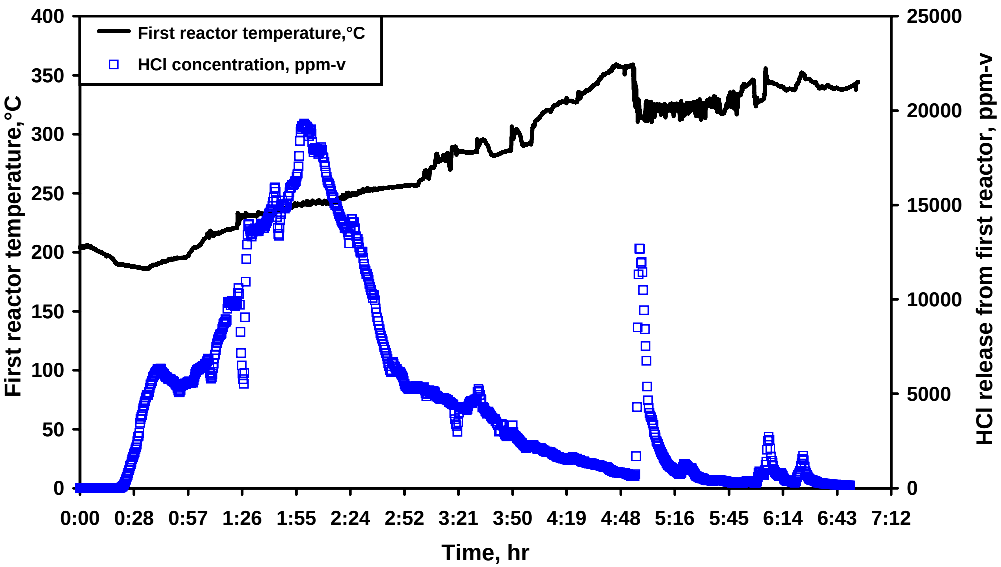


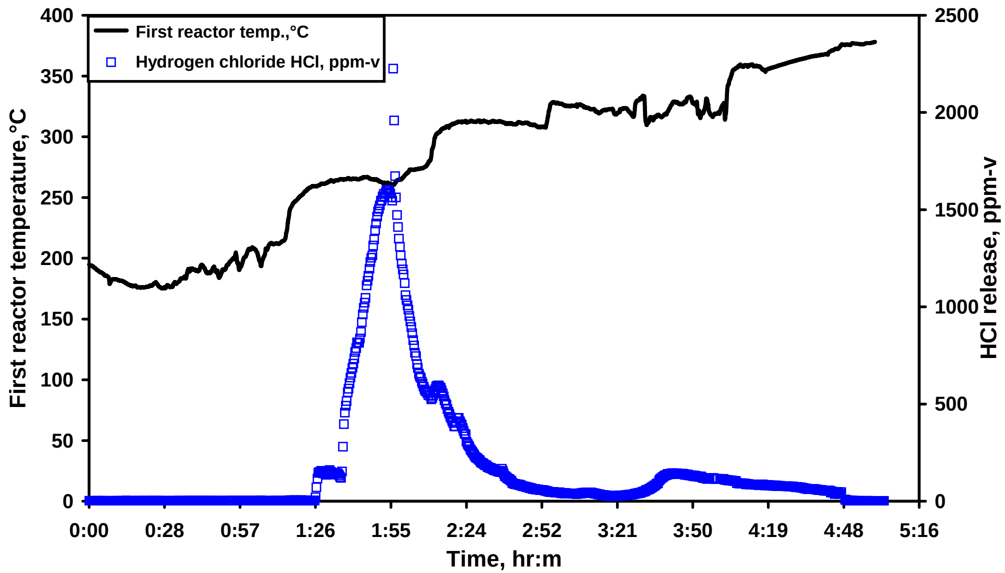
Properties of the bottle-grade PVC, wood (pine) and Polish coal

Substance	Bottle-grade PVC	PVC waste 1 (sewage pipe)	PVC waste 2 (sewage pipe)	Wood (pine)	Polish coal
Ultimate analysis (%-wt, dry)					
C %-wt	42.51	37.89	36.86	50.2	82.32
H%-wt,	5.35	4.82	4.54	6.00	5.12
N%-wt,	NA*	NA	NA	0.30	1.42
S%-wt,	NA	NA	NA	NA	0.77
O%-wt,	1.08	NA	2.67	43.2 (diff)†	10.4 (diff)
Cl%-wt, l	50.93	52.28	53.54	NA	NA
Sn%-wt,	0.17	< 0.002	NA	NA	NA
Pb%-wt,	NA	4.00	0.63	NA	NA
Cd (mg/kg),	NA	< 1	< 5	NA	NA
Ca%-wt,	NA	0.04	1.62	NA	NA
Zn (mg/kg)	NA	36	13	NA	NA
Sum	100.04	99.03	99.88	100	100
Proximate analysis (%-wt)					
Fixed carbon	~92+			7.50	NA
Volatile	~8+			84.2	NA
Moisture	0			8.00	6
Ash	0			0.30	8.3
Higher heating value MJ/kg	NA			20.7	NA
Lower heating value MJ/kg	NA			19.4	NA

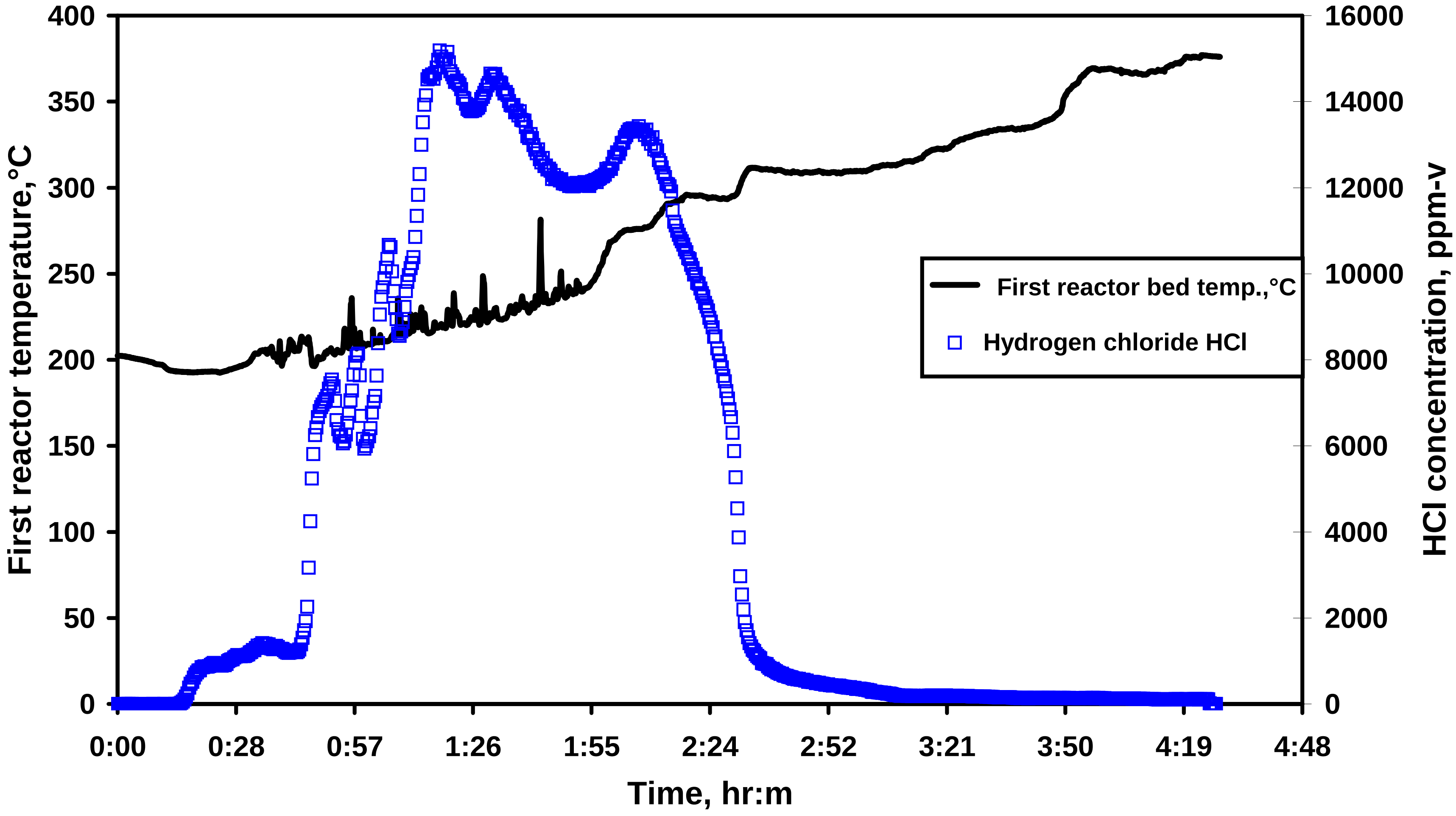
* Not analyzed, + Assumed, from (Zevenhoven et al., 2002), † Oxygen is calculated by difference not measured

Release of HCl and BFB reactor temperature versus time for bottle-grade PVC & sewage PVC waste 1

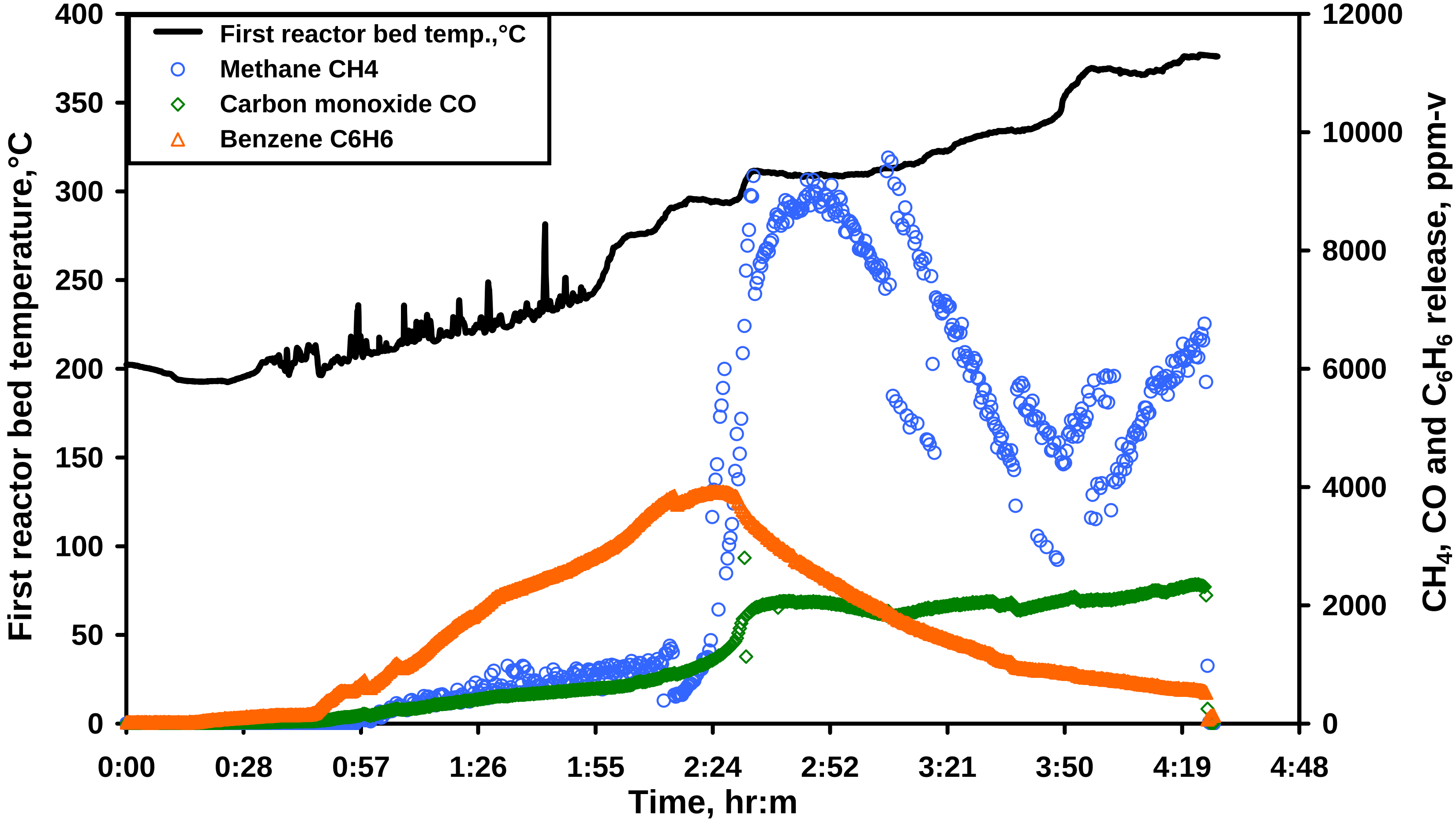




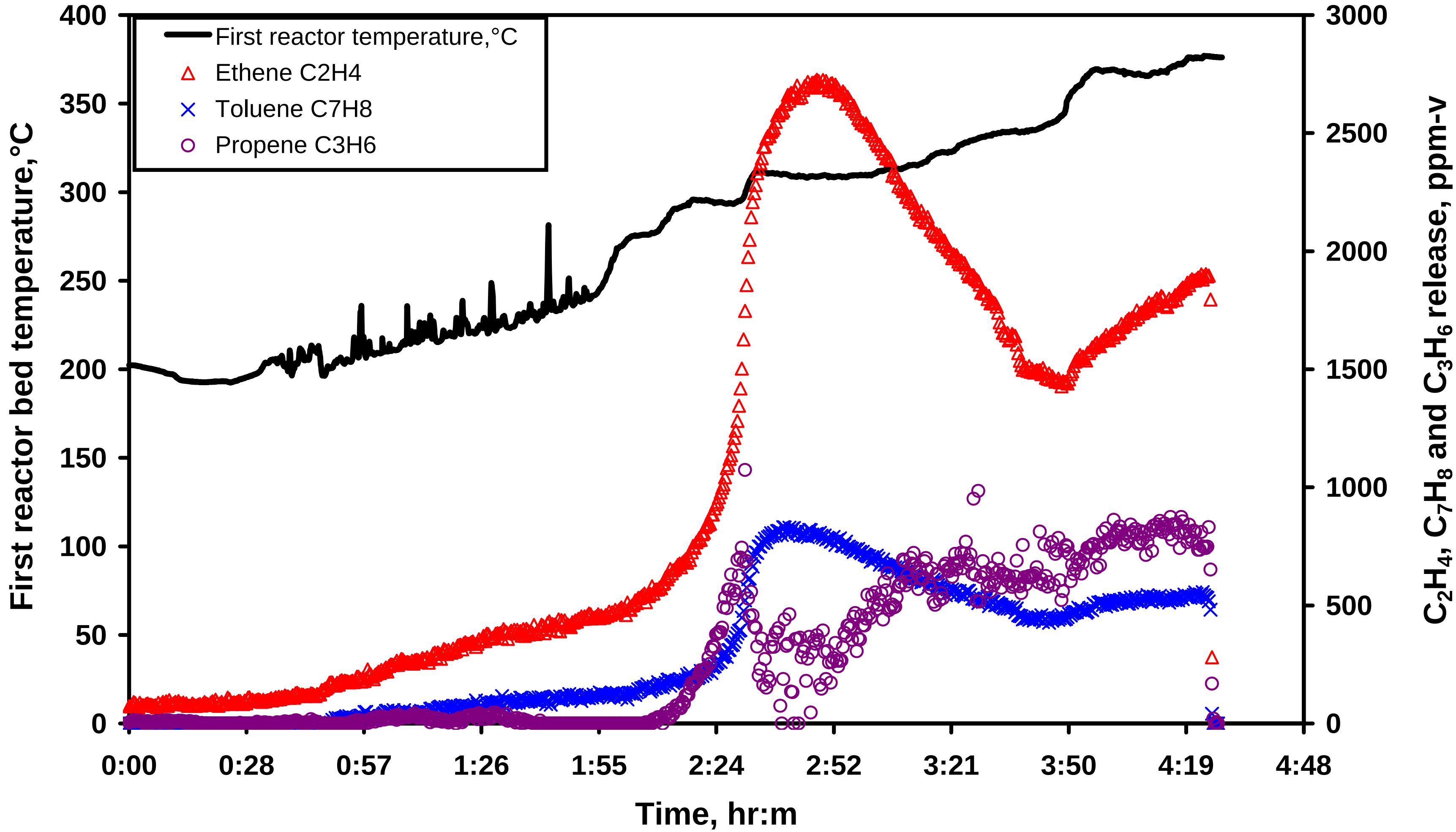
HCl released from sewage pipe PVC waste 2



Other vapors release from BFB for real PVC No.2



Other vapors release from BFB for real PVC No.2

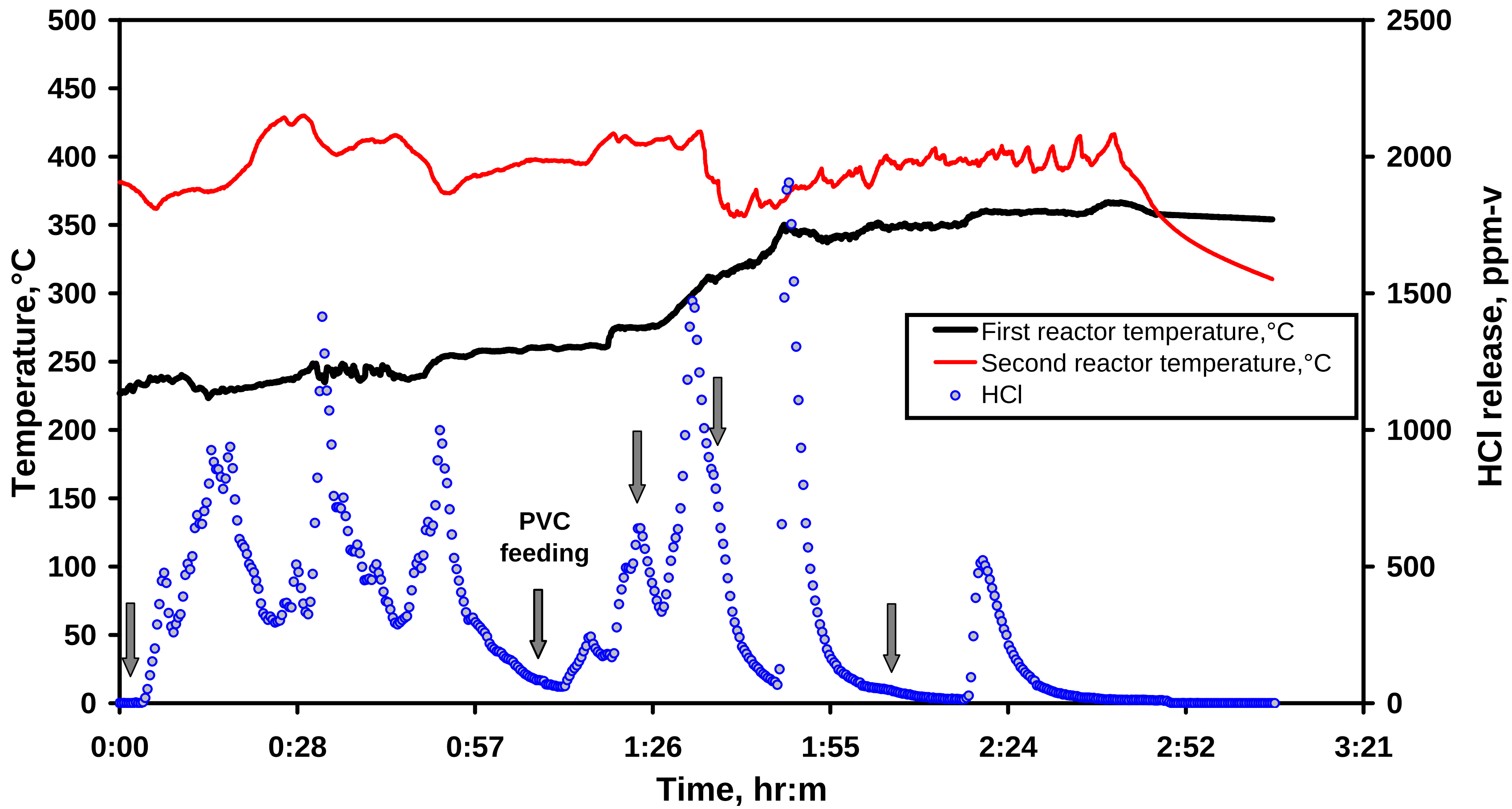


Chemical analysis of (dry) char samples taken from the pyrolysis reactor (BFB) after the tests, for bottle-grade PVC, PVC waste No.1 and PVC waste No.2

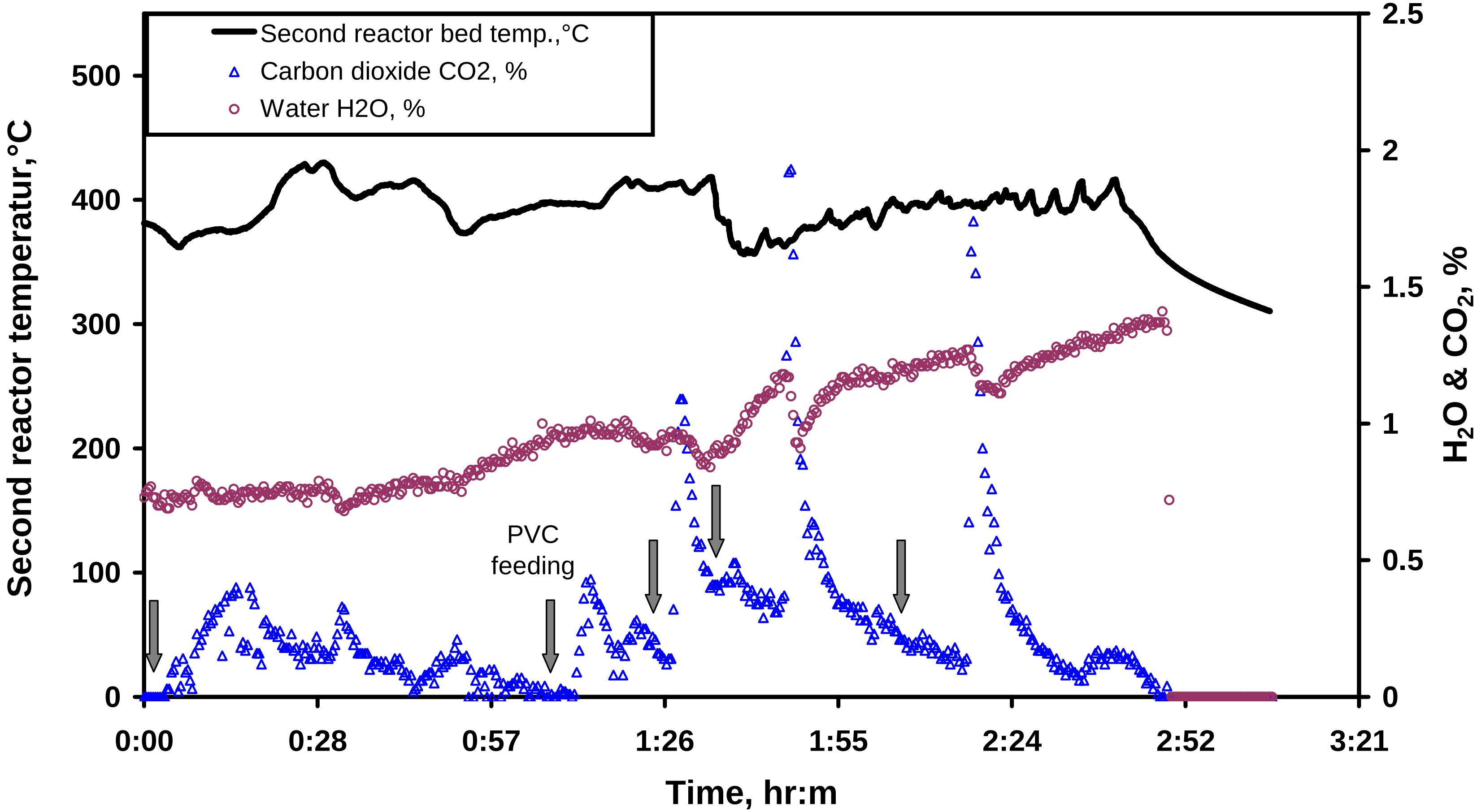
Substance	Bottle-grade PVC		PVC waste 1 (sewage pipe)	PVC waste 2 (sewage pipe)
	Top of the bed	Middle of the bed		
C (%-wt)	31.4	15	14.2	6.6
H (%-wt)	2.3	0.9	1.0	0.4
O (%-wt)	NA	NA	NA*	1.6
Cl (%-wt)	0.03	0.008	0.4	0.8
Sn (%-wt)	NA	NA	NA	NA
Pb (%-wt)	NA	NA	1.6	0.2
Cd (mg/kg)	NA	NA	NA	NA
Ca (%-wt)	NA	NA	NA	0.8
Zn (mg/kg)	NA	NA	NA	0.03
Bed material (%-wt)**	66.3	84.1	82.8	89.6
Sum %-wt	100.0	100.0	100.0	100.0

*NA = not analysed ** By difference

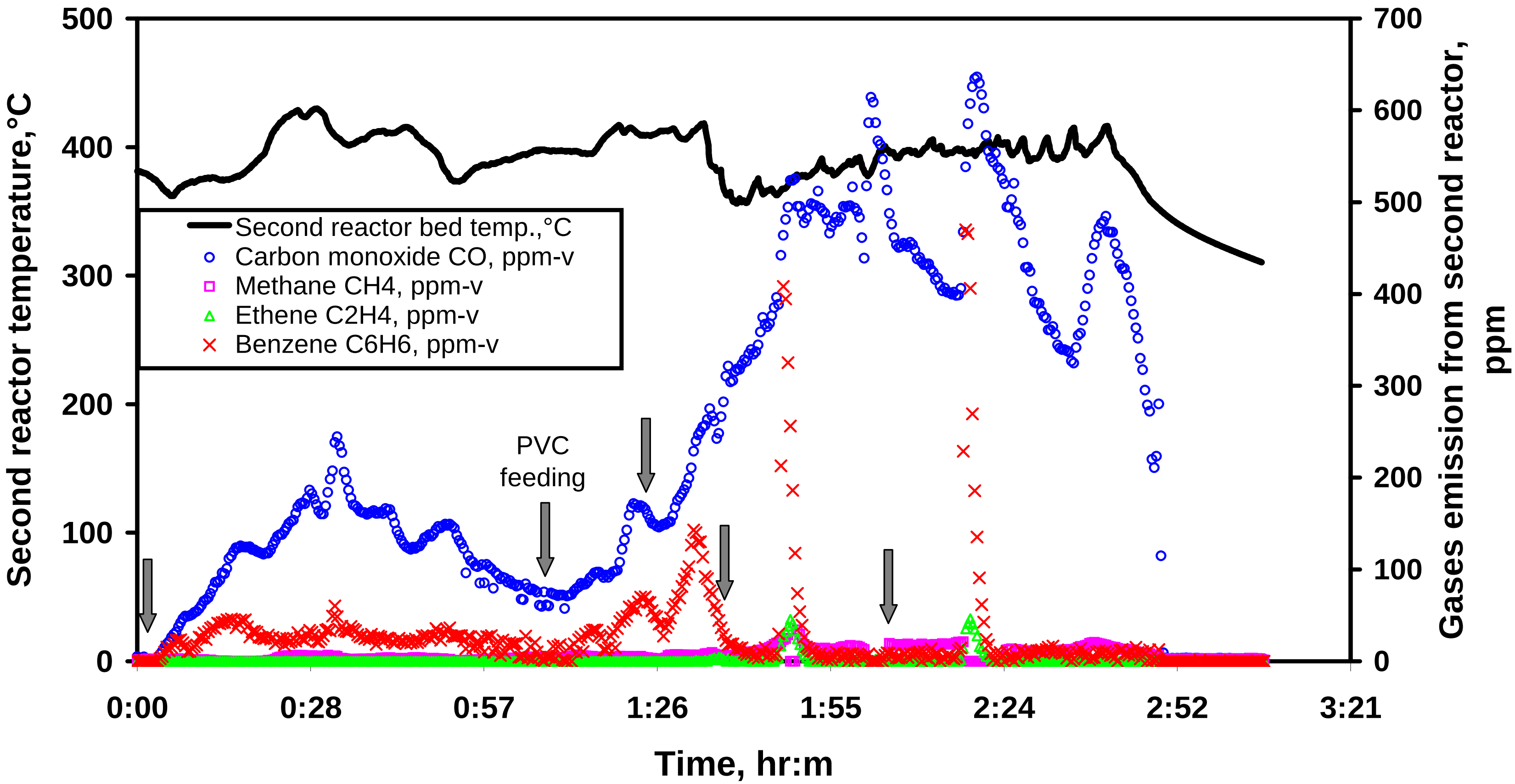
HCl emission from CFBC for bottle-grade PVC



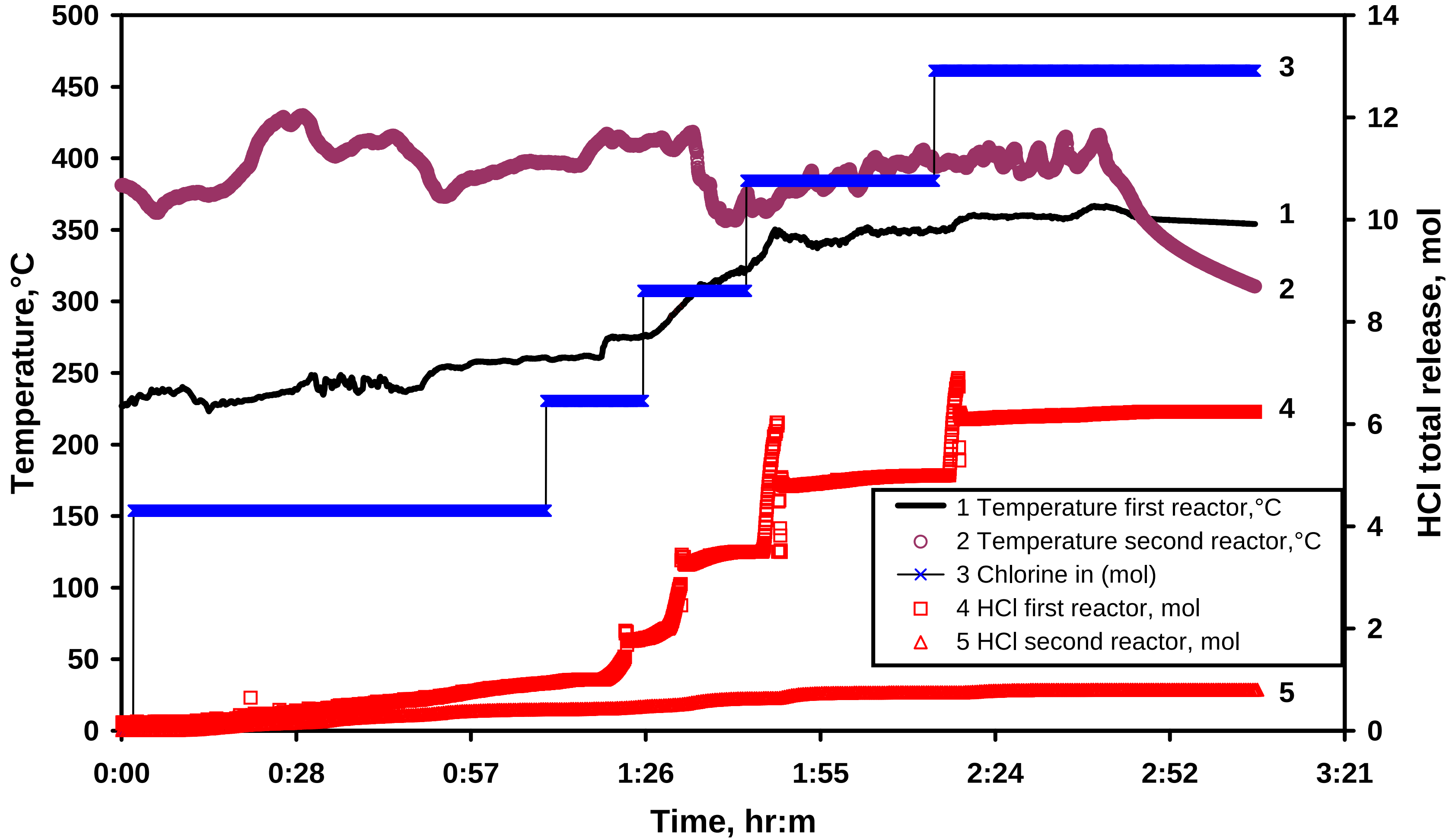
CO_2 & H_2O release from CFBC for bottle-grade PVC



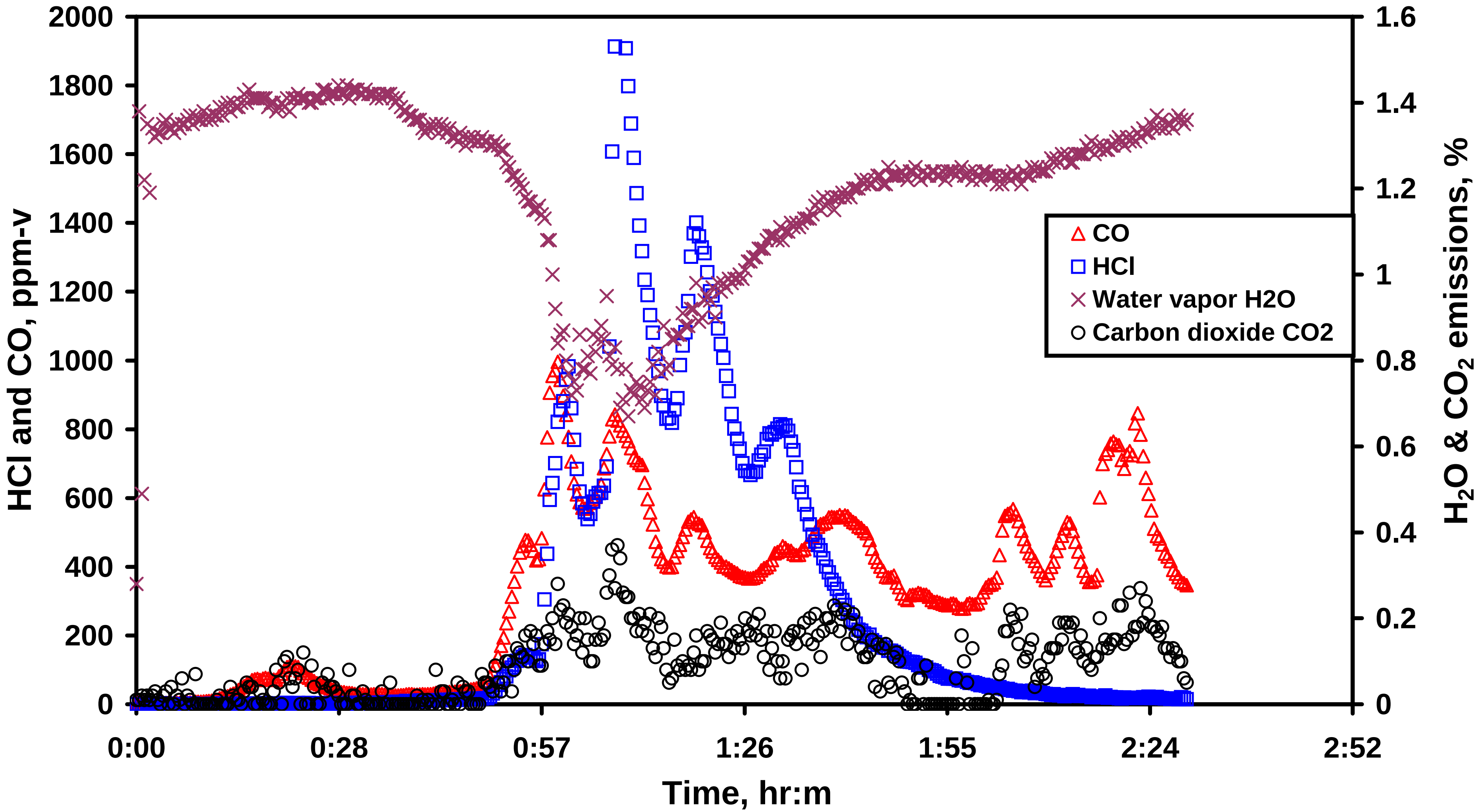
Other vapors release from CFBC for bottle-grade PVC



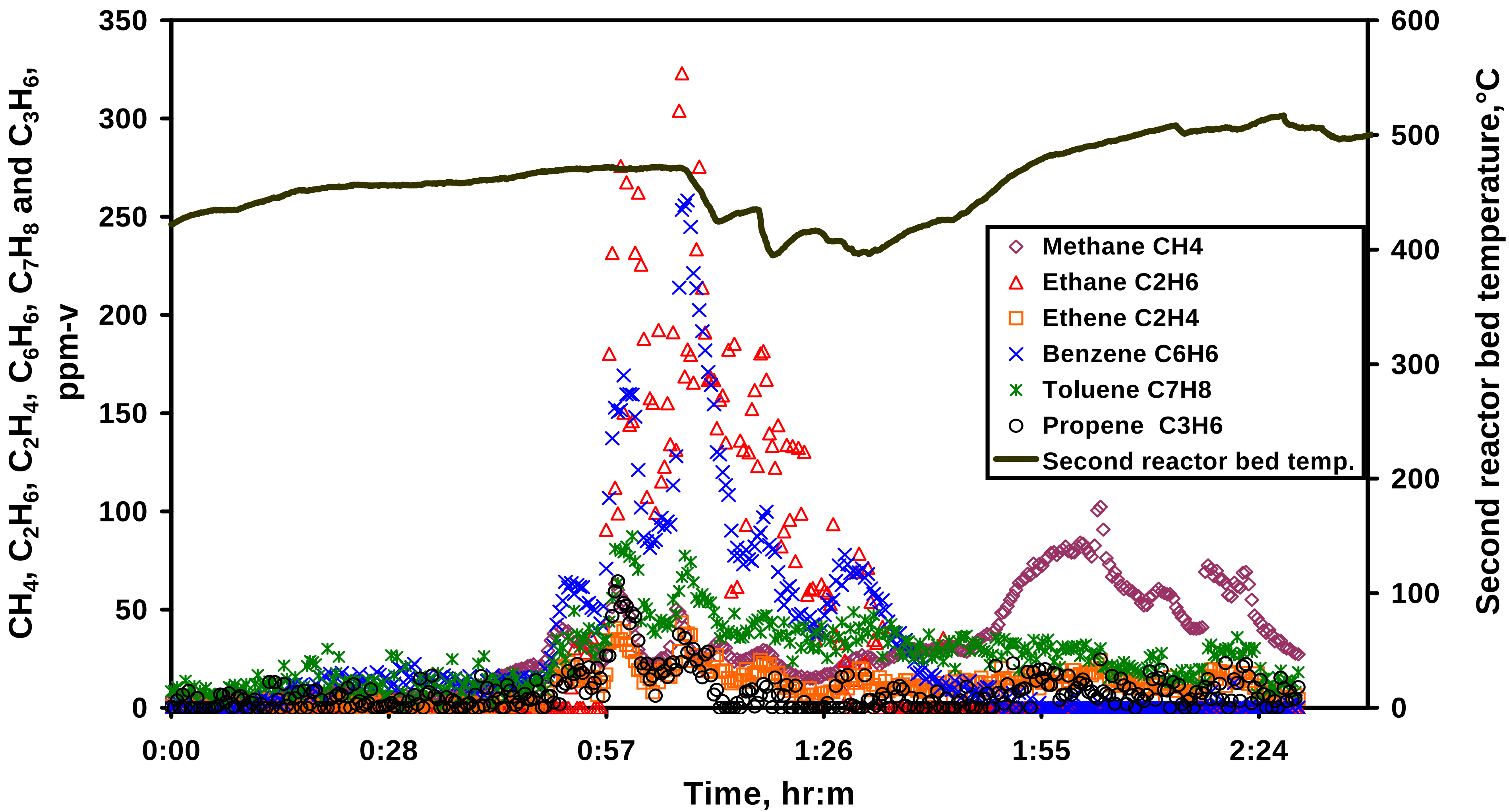
HCl release from bottle-grade PVC No.2 in the BFB & CFBC



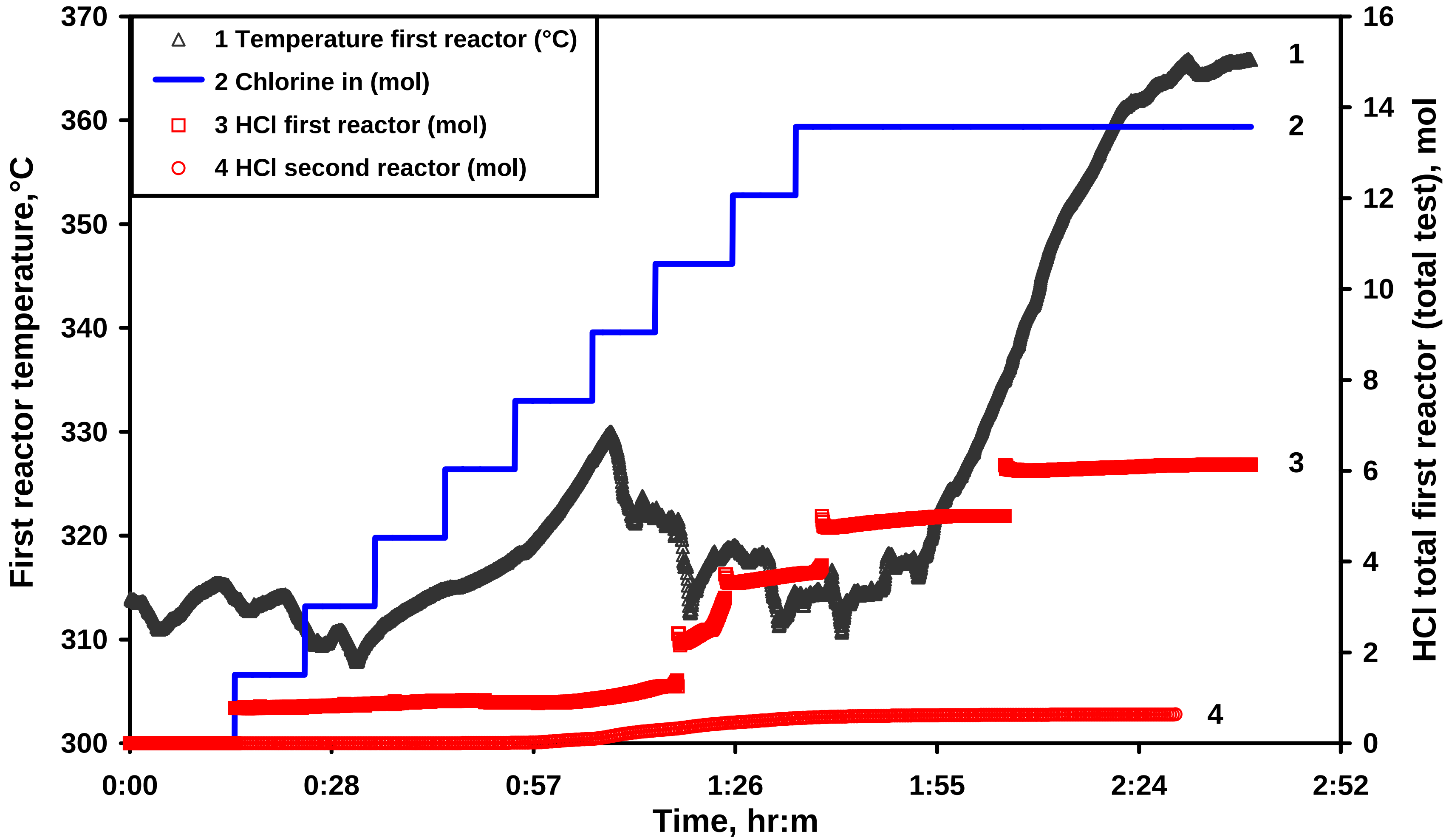
HCl, CO, H_2O & CO_2 emission from CFBC (PVC sewage pipe No.2)



Other vapors from CFBC (PVC sewage pipe No.2)



HCl release from real PVC No.2 in the BFB & CFBC



Analysis result for the dioxins, furans and other chlorinated compound (char from PVC waste 2)

Compounds	Char (ng/g)	I-TEQ (ng/g)
Dioxins (PCDD):	**0.780**	**0.155**
Furans (PCDF):	**2.51**	**0.35**
Polycyclic aromatic hydrocarbon (PAH)	**23180**	
Chlorinated phenols	**352**	
Polychlorinated biphenyls (PCB)	**all < 10**	
Polychlorinated benzenes	**149**	

Conclusions

- A lab-scale facility was built for wastes containing large amounts of PVC, using the fact that PVC de-hydrochlorination is complete at temperatures of 300-350°C.
- The Cl content in the char for the two-stage combustion test using 100% bottle-grade PVC was below 0.1%-wt (from 51%-wt in the PVC), at chlorine-to-carbon mass ratio < 0.001 kg Cl / kg C.
- The two-stage combustion test with 100% waste PVC (sewage pipe) shows that the char chlorine content 5%-wt (from 54%-wt in the PVC) at chlorine-to-carbon mass ratio < 0.06 kg Cl / kg C can be produced.
- Very small amounts of PCDD (0.78 ng/g, 0.155 ng TEQ/g) and PCDF (2.5 ng/g, 0.35 ng TEQ/g) TEQ/g) were found in the char
- PVC stabilizer type and the fractional weight of the stabilizer has a large effect on the behavior of PVC waste de-hydrochlorination at 200-400°C, specially lead based stabilizers, cadmium compounds (Cd) stabilizers *etc*.
- The temperature in CFBC was not enough to burn the char. Electrical heaters must be added to the CFBC beside the air preheater.

Final Remarks

- PhD defense Loay Saeed June 18th, 2004, Espoo, Finland
- The test facility has won a year 2004 Facility Recognition Award of the ASME (American Society of Mechanical Engineers) Solid Waste Processing Division.

ACKNOWLEDGEMENTS

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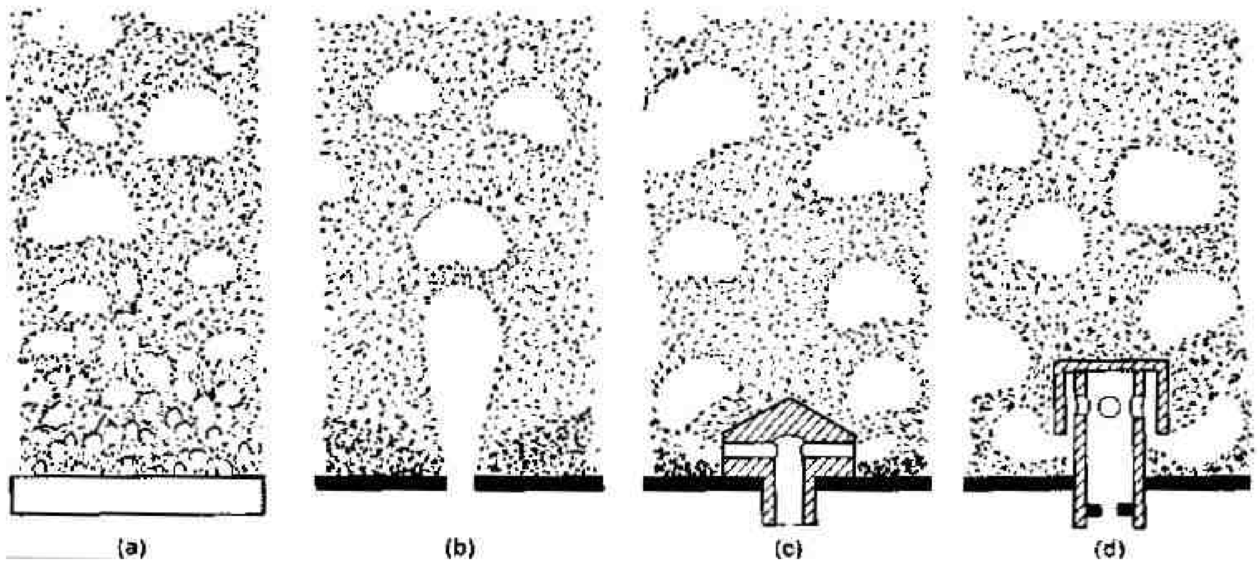
- HUT technicians Pertti, Risto, Seppo, Taisto, Vadim
- Temet Oy, Matti Haapala, Helsinki

Behavior of bubbles just above the distributor



Porous plate **Perforated plate** **Nozzle-type tuyere** **Babble cap tuyere**

The Desired Properties of the Distributor

- Uniform and stable fluidization over the entire operation
- Minimum attrition of bed material
- Minimum erosion of bed internals or heat exchanger tubes tubes
- Minimum back-flow of solids into the plenum chamber
- Minimum amount of dead zone on the distributor
- Minimum plugging over extended periods of operation