Air Purifying Cartridge Sensor Integration Approach for Active End of Service Life Indication

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Objective

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- Determine an approach for "active" direct in bed measurement of chemical penetration in an air purifying filter.
- Identify characteristics of an ESLI system required for successful operation.
- Demonstrate performance of a prototype approach for ESLI and residual life indication (RLI).

ESLI Requirements | Regulatory

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	ESLI Required / Recommended	ESLI Specific Requirements	ESLI Indirect Requirements
ISO 16975 - Respiratory Protective Devices - Selection, Use, and Maintenance	x		
JIS T8152_2002 (Japan)			
GOST R12.4.192-99 (Russia)			
EN 14387:2008 (CEN)			x
ANSI Z88.2-1992	x		
AS/NZS 1715:2009 | AS/NZS 1716:2003 (Australia/New Zealand)			
EN 529:2005 (CEN)			
OSHA 1910.134 (USA) [NIOSH STP]	x		
Concept PAPR Standard Subpart P (USA)	x	x	x
GB2890:2009 (China)	x		

ESLI Requirements | NIOSH NPPTL

- (Paraphrased) ESLI Criteria
  - 1. Data Requirements [RCT-APR-STP-0066 (NPPTL)]
    - **1.1 End point when cartridge has at least 10% service life remaining.**
    - 1.2 Desorption of any impregnating indicator agents
    - 1.3 Interferences
    - 1.4 Potentially hazardous exposure resulting from reaction of ESLI and gases.
    - 1.5 Shelf Life & Storage Conditions
    - **1.6 Flow-Temperature Results, 2 RH points, 2 contaminant levels**
  - 2. Passive ESLI Requirements [RCT-APR-STP-0061 (NPPTL)]
    - 2.1 Readily visible without manipulation.
    - 2.2 Change detectable to those with color blindness.
    - 2.3 Reference colors adjacent to indicator
  - 3. General Requirements
    - 3.1 Shall not interfere with face seal.
    - 3.2 Shall not change weight distribution of respirator.
    - 3.3 Shall not interfere with lines of sight.
    - 3.4 Any ESLI not discarded with the cartridge / shall withstand cleaning.
    - 3.5 Replaceable ESLI shall be easily removed and replaced without special tools.
    - 3.6 Adequate labeling of use conditions
    - 3.7 Adequate use instructions.

ESLI Requirements | Functional

- Functional Components
  - Alarm
    - Indicate end of service life
    - Indicate residual service life
  - Logic and memory
    - Algorithm to interpret sensor data and trip alarm
    - Memory for trend data storage and calculation parameters.
  - Data exchange
    - Means to exchange data between components of the ESLI system and the respirator.
  - Power source
  - Sensor
    - Preferably reusable on cartridge change-outs
    - Chemical
    - Environmental (RH, T, flow rate)

ESLI Requirements | Chemical Sensor

Criteria	Nominal Target
Shelf life	3 – 10 years
Size	125 mm3
Cost	Commercially acceptable
Maturity	TRL 9
Stability	Minimal drift
Response time	< 30 seconds
Selectivity	Dependent on approach
Sensitivity	Dependent on measurement location 100 ppb traditional / 1-10 ppm pESLI
Dynamic Range	3 orders of magnitude
Reversibility	Sensor must recover if it is to be reused, otherwise it does not matter.

ESLI Requirements | Chemicals of Interest

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- Chemicals of interest may be based on specific hazard, industry segments, or existing regulatory groupings.
- For some groupings detection of any chemical within a group is all that is required, identification is not necessary.
- For standard industrial usage per global respiratory selection guidelines the hazard should be well known and identified as part of a well managed respiratory protection program.
- Organic vapor selectivity is both a function of toxicity but also relative loading potential on activated carbon.

Chemical contaminant
Ammonia
Hydrogen Cyanide
Hydrogen Sulfide
Organic Vapors
Sulfur Dioxide
Chlorine
Hydrogen Chloride
Formaldehyde
Hydrogen Fluoride
Acrolein

Chemical groupings
Wildland fire & overhaul
AS / EN - ABEK
AS / EN - A
NIOSH MPC [common offerings]
CBRN
Oil & Gas
NIOSH organic vapor
AS / EN - ABE
OSHA 1910.1000 [high hazard chemicals]

ESLI | Past Technical Difficulties

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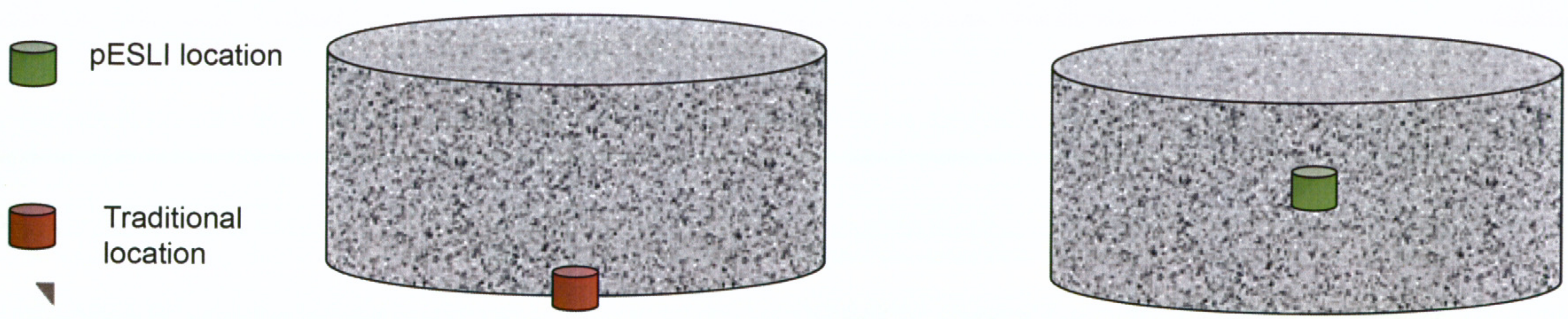
- Requires high sensitivity sensor to detect PELs.
- Integration of sensor into sorbent bed without negatively impacting service life.
- Keeping through life cost of ESLI system acceptable.

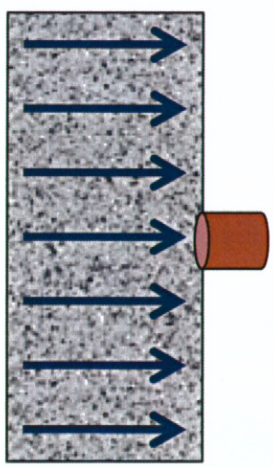
Approach – proactive End of Service Life with Sensor Post Technology

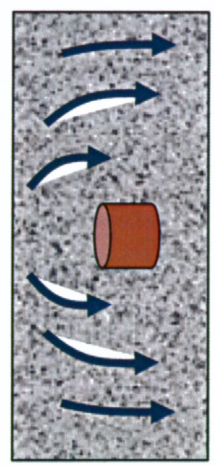
- Traditional active sensor approaches either place the sensor immediately after the sorbent bed or in the outlet end of the sorbent bed with no method to remove the sensor after use. Sensor must have high sensitivity and only provides ESLI.
- Our approach is to place the sensor toward the inlet end of the bed near but not beyond the critical bed depth region.
- The breakthrough is detected earlier; the shape of the breakthrough curve is different; stiochiometric breakthrough will be observed.
- Sensor data from this new location is used to estimate the breakthrough time at the outlet of the bed.
- This provides both residual and end of service life.

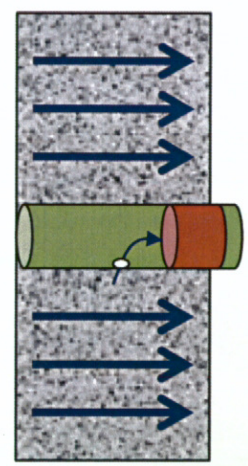


Approach – proactive End of Service Life with Sensor Post Technology

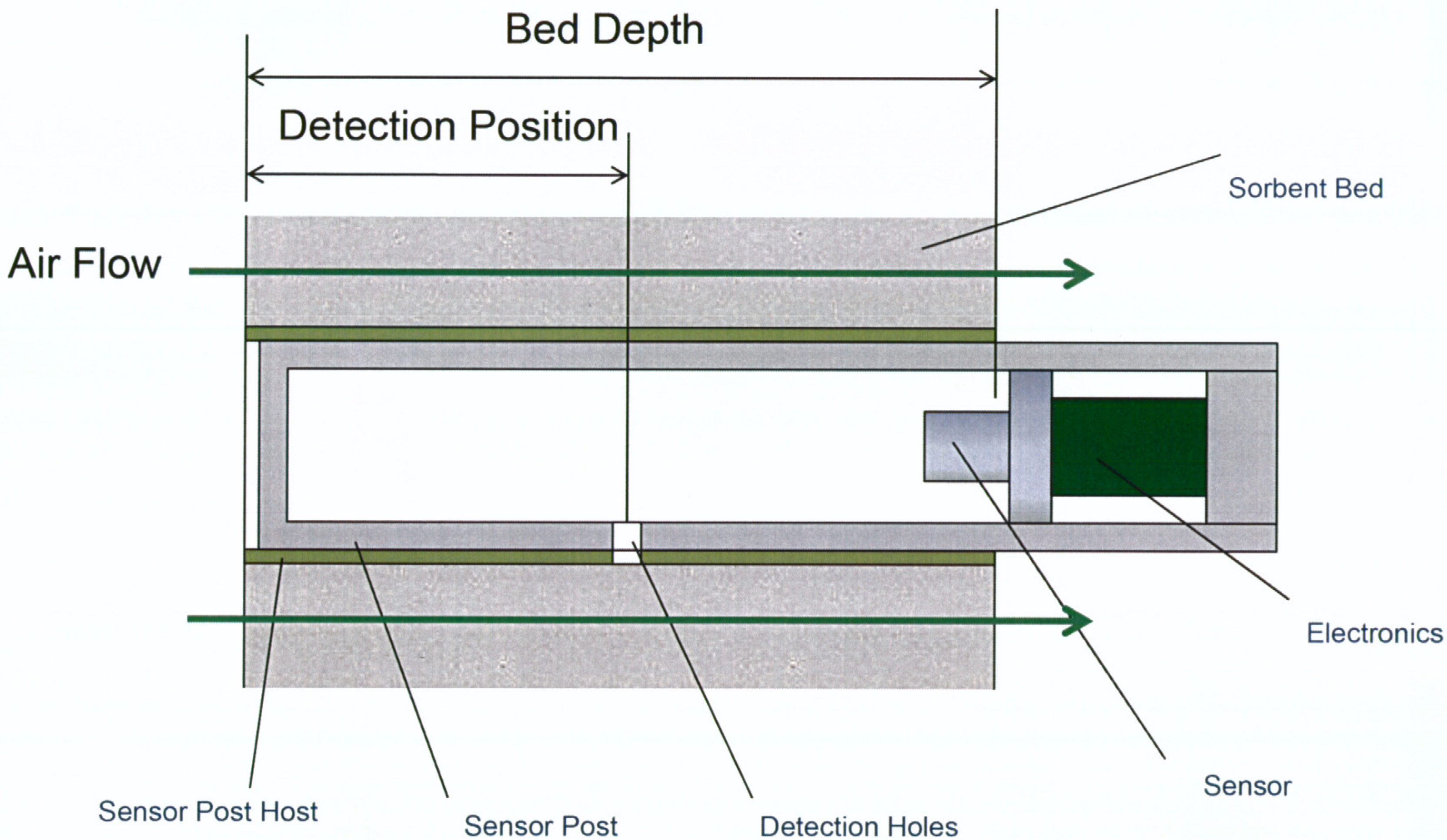
- Traditional approaches of sensor locations:
  - Behind the cartridge
  - Inside the cartridge
- Sensor not reusable
- Embedding sensor inside the bed blocks the flow and results in uneven flow.
- Our new approach: Sensor Post
  - A removable sensor post that can be re-used on cartridge change-outs
  - Will not block air flow (hence not down-grading cartridge performance)
  - Precisely controlled detection point regardless of the location of the sensor



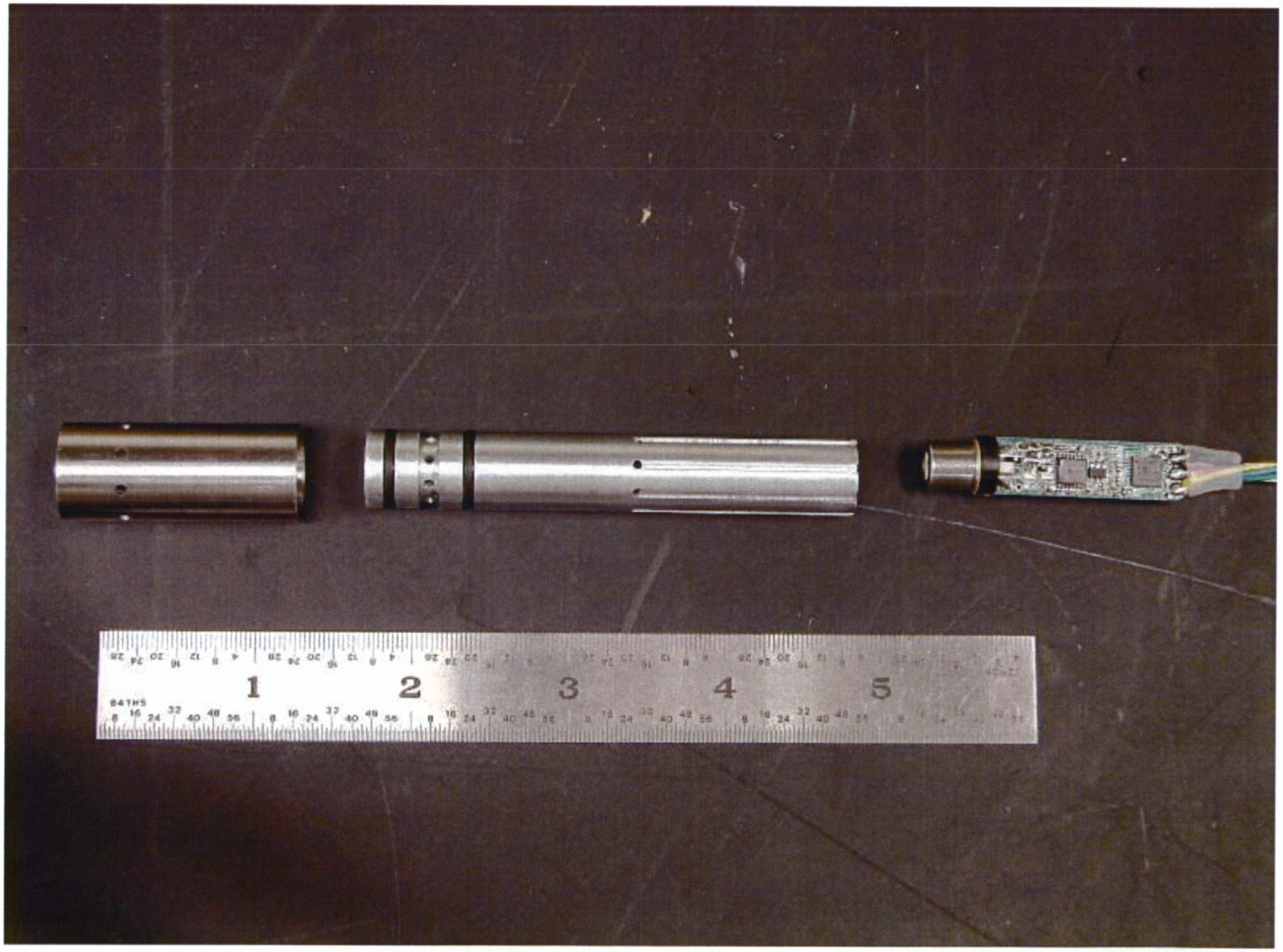




Sensor Post Location

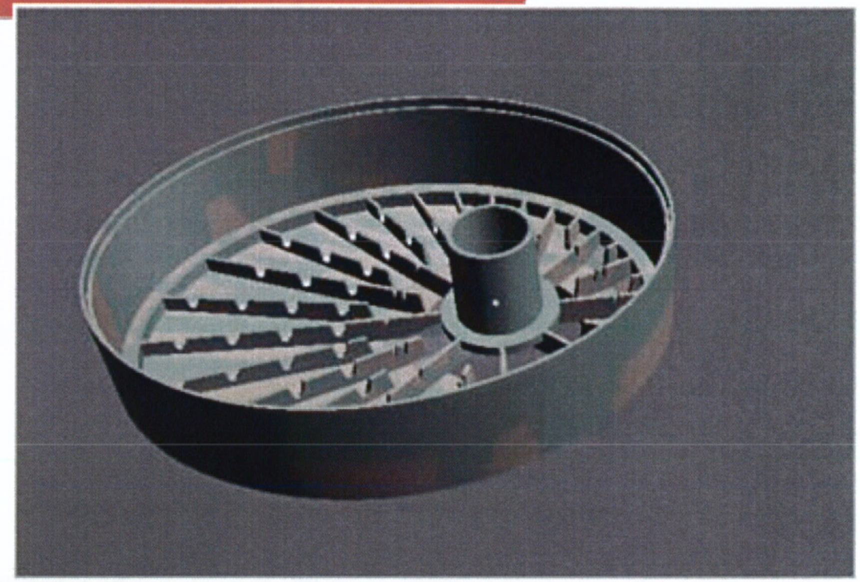


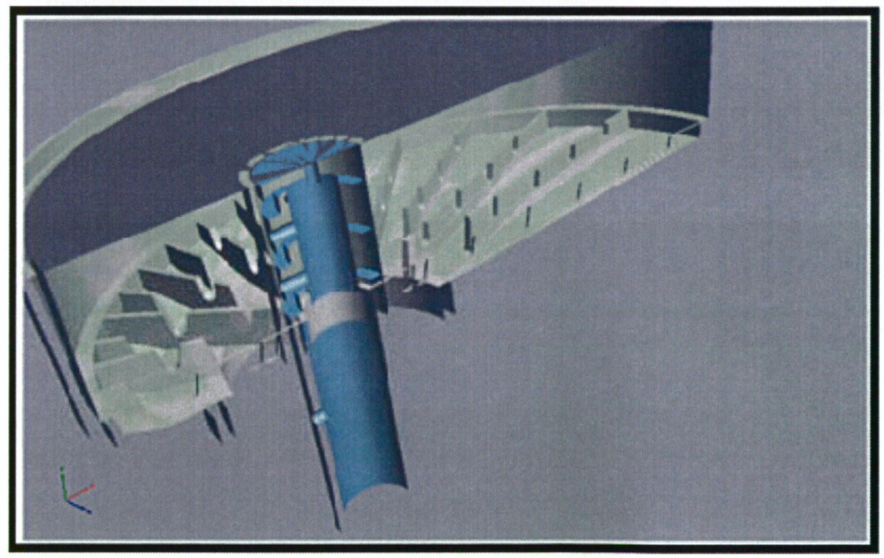
Sensor Post Prototype



ESLI Prototype Testing

- Prototype filter is designed a refillable cartridge with built-in sensor post host
- Prototype sensor post is designed as a cylindrical object enclosed with a sensor and digital signal conditioner
- Seals are used to prevent any leak through the sensor post host





Approach– Sensor Integration

- Not only should the sensor integrate into the bed without impacting performance, it should be reusable. Our approach is to use a sensor post.
- The sensor post is a removable housing which is attached to the respiratory protection device inlet.
- A filter must be used with matching cavity.
- The cavity penetrates fully through the sorbent bed to help flow distribution.
- The sensor post can contain one or more sensor ports (capped with membrane).
  - Sorbent bed sensor ports for chemical sensor(s).
  - Inlet sensor port for environmental sensors (RH, Temperature, flow rate).

Detecting Hole Location:

- Trade off between Earlier Warning and More Accurate Forecast
  - The closer the detection point is to the cartridge inlet, the early it gets the RLI information, but the less accurate the forecast ESLI
- If no Residual Life Indication (RLI) is required, the sensor can be located to the exact position where >10% of service time remains

ESLI Forecasting:

- The prototype is tested with two chemicals: Ammonia (300 ppm) and Hydrogen Sulfide (100 ppm)
- Sensor post signal is sampled, modeled, and used to forecast service life (hence ESLI)
- The forecasted service life is compared with the actual service life detected with an external sensor

RLI and ESLI Forecasting: Conceptual Testing

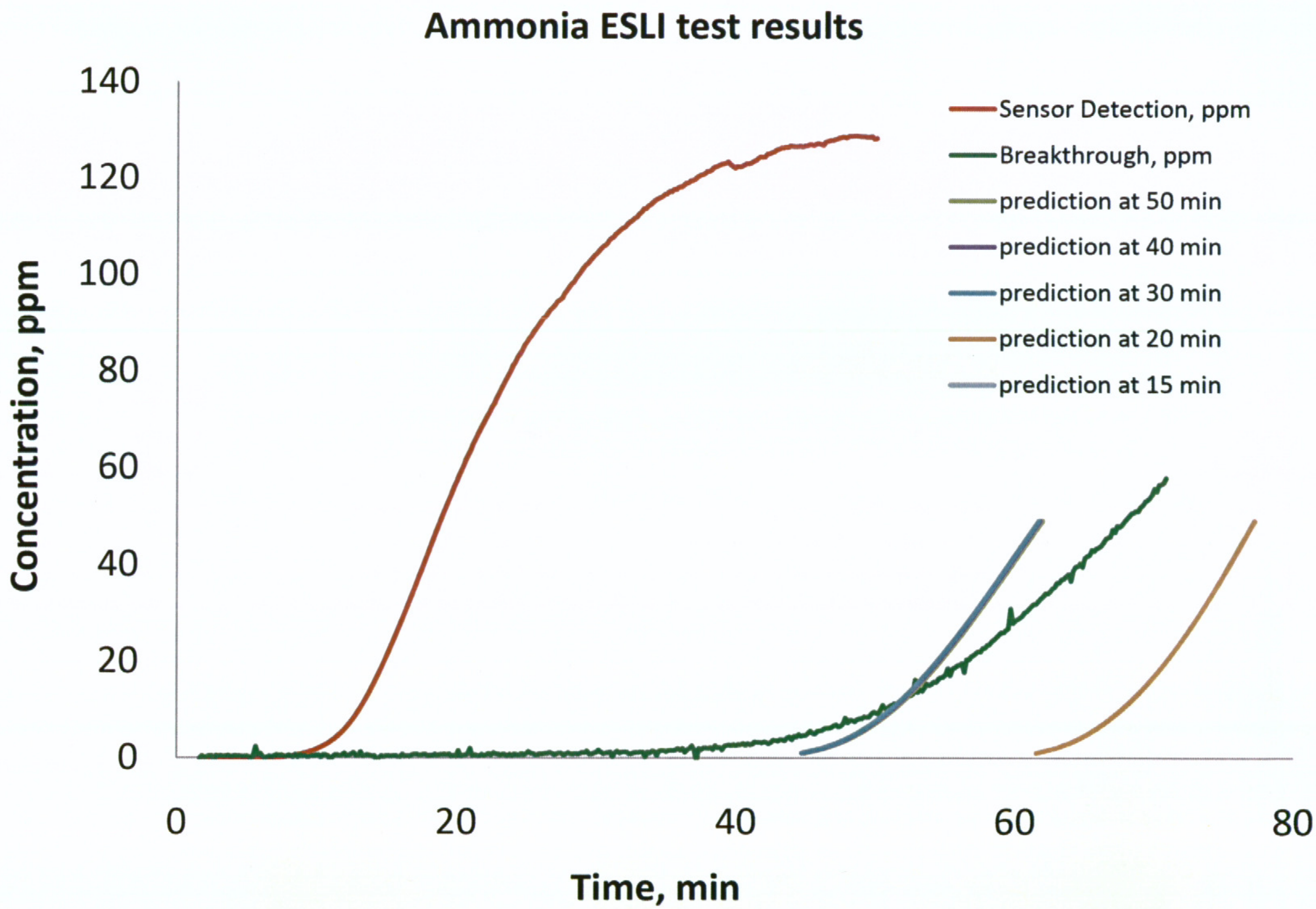
- Using breakthrough model* to collect fundamental breakthrough wave parameters

  $$Ln(\Phi) = \tau^{\varsigma} Ln(\Phi_s)$$

- Extend the breakthrough wave to the end of the bed and thus forecast the service life
- The more data the sensor collects, the more accurate the forecast will be
- Forecast can be made instantly by the built-in microcontroller

*Ding, Parham, Staubs, 2008 ISRP, Dublin, Ireland

ESLI Conceptual Testing



ESLI Forecasting: test results

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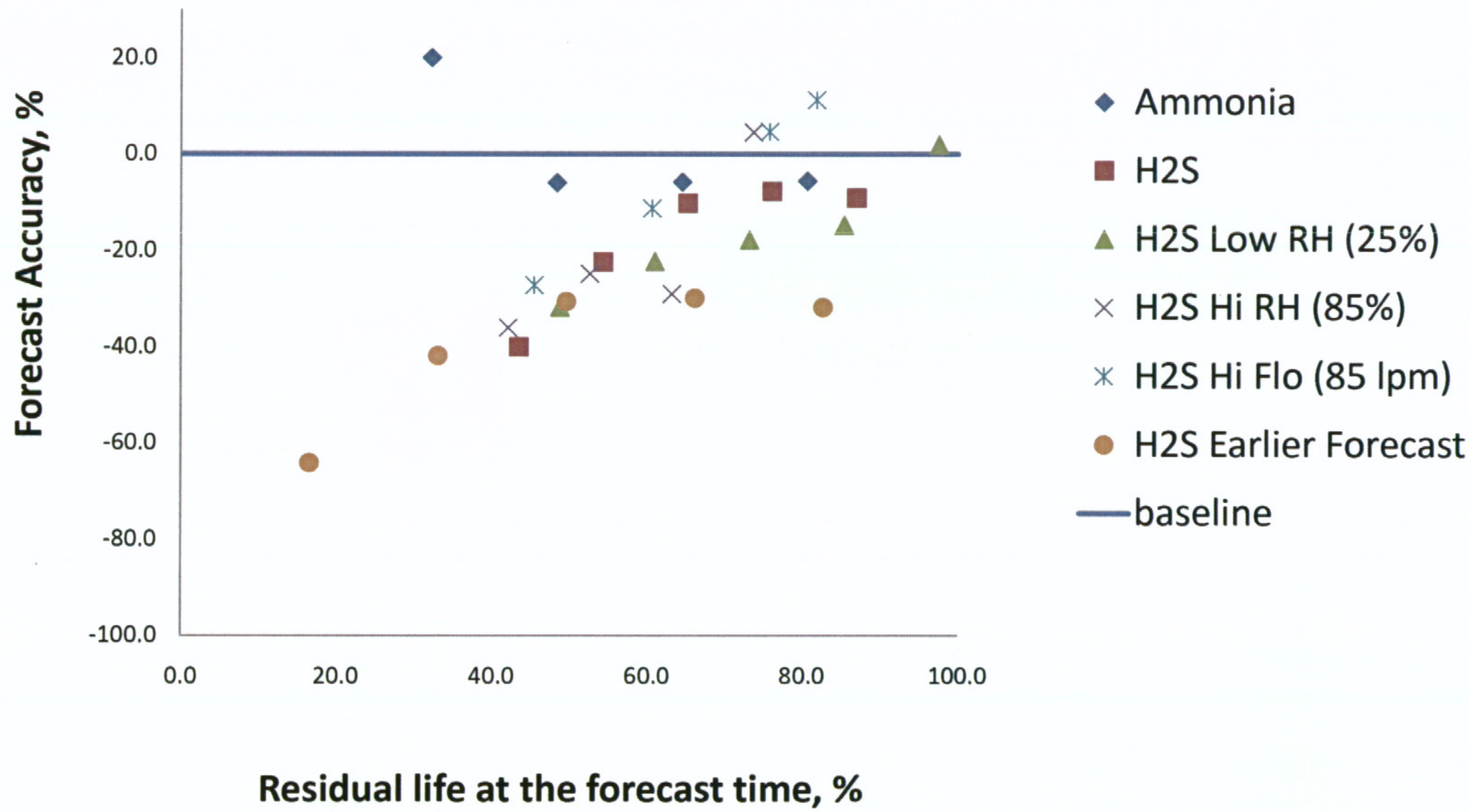
Chemical	RH, %	F, lpm	Location						
AM	50	64	1/2 of bed	Forecast Time, min	20.0	30.0	40.0	50.0	
				Forecasted ESLI, min	74.4	58.3	58.4	58.5	
				Actual ESLI, min	62	62	62	62	
H2S	50	64	1/2 of bed	Forecast Time, min	20.0	25.0	30.0	35.0	40.0
				Forecasted ESLI, min	27.6	35.7	41.3	42.4	41.8
				Actual ESLI, min	46.0	46.0	46.0	46.0	46.0
H2S	25	64	1/2 of bed	Forecast Time, min	20.0	25.0	30.0	35.0	40.0
				Forecasted ESLI, min	28.0	31.8	33.7	34.9	41.8
				Actual ESLI, min	41.0	41.0	41.0	41.0	41.0
H2S	85	64	1/2 of bed	Forecast Time, min	20.0	25.0	30.0	35.0	40.0
				Forecasted ESLI, min	30.4	35.7	33.7	49.6	41.8
				Actual ESLI, min	47.5	47.5	47.5	47.5	47.5
H2S	50	85	1/2 of bed	Forecast Time, min	15	20	25	27	
				Forecasted ESLI, min	24.0	29.3	34.5	36.7	
				Actual ESLI, min	33	33	33	33	
H2S	50	50	1/3 of bed	Forecast Time, min	20.0	40.0	60.0	80.0	100.0
				Forecasted ESLI, min	43.4	70.3	83.9	84.8	82.5
				Actual ESLI, min	121	121	121	121	121

ESLI Forecasting: test results



Summary

- Use of a reusable sensor post improves the readiness of active ESLI technology.
- Reuse changes the cost structure and allows for calibration and maintenance.
- Key concept is transformation of in bed concentration measurement in both time and position.
- Precise sensor location: trade-off between earlier warning and more accurate ESLI
  - Dual sensor approach can catch both thus is our preferred approach

Questions?

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