2016 Purdue Conferences
Compressor Engineering
Refrigeration and Air Conditioning
High Performance Buildings

A Literature Review on Air Side Heat Exchanger Fouling in Heating, Ventilation and Air-Conditioning (HVAC) Applications

Omer Sarfraz, Christian Bach

Building & Environmental Thermal Systems Research Group (BETSRG)
Mechanical and Aerospace Engineering
Oklahoma State University

July 11 -14, 2016

Center for High Performance Buildings at Purdue

Introduction

- Extensive use of air to refrigerant heat exchangers in residential, commercial and industrial applications.
- Increased interest in the use of air cooled systems as an alternative to water cooled systems.
- Due to extensive use of air cooled heat exchangers in HVAC applications, It is important to analyze the fouling phenomenon in these systems.

Introduction

- Fouling mechanisms and agents
  - » Accumulation and growth of particles on heat exchanger (HX) surface.
  - » Inorganic materials as well as organic materials.
  - » Dependent on HX design and particular process in which it is used.
- Fouling effects
  - » Decrease in heat transfer.
  - » Hindrance to air flow - increase in air side pressure drop.
  - » Increases fan power.

Fouling Phenomenon

- Fouling phenomenon can be divided into (Awad,2011):
  - » Particulate fouling

    Accumulation of suspended particles in the fluid stream on the heat exchanger surface.
  - » Precipitate fouling

    Due to the presence of dissolved salts in the saturated solution.
  - » Chemical reaction fouling

    Due to the chemical reaction that takes place between the particles BC1 LU7 present in the fluid stream. Heat exchanger surface can act as a catalyst.

Slide 4

BC1 does this include reaction with the surface? What about corrosion?
Bach, Christian, 6/29/2016

LU7 corrosion is seperately listed
Lab User, 6/29/2016

Fouling Phenomenon

- Fouling phenomenon can be divided into (Awad,2011):
  - » Corrosion fouling

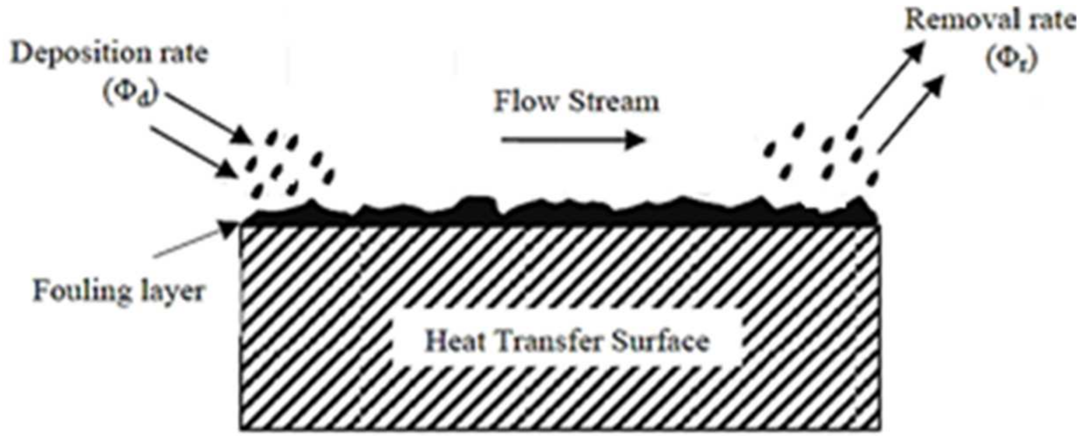
    Due to electrochemical reactions that can take place between heat transfer surface and fluid stream.
  - » Biological fouling

    Due to the presence of biological matter in the fluid stream.
  - » Freezing fouling/Frosting

    Due to the freezing of liquid on heat transfer surface like frosting of heat exchangers during winter.

Fouling Phenomenon

- Main fouling mechanisms, air-cooled heat exchangers (Siegel & Nazaroff, 2003):
  - » Particulate fouling,
  - » Biological fouling,
  - » Freezing fouling.



Fouling Process (Awad, 2011)

- The fouling rate is the difference between deposition rate, Φ_d and removal rate, Φ_r (Awad, 2011)

Fouling Phenomenon

- Siegel & Nazaroff (2003) developed a model for the particles deposition onto the heat transfer surface.
- The overall deposition fraction η is:

$$\eta = 1 - P_{\mathrm{fin}} \cdot P_{\mathrm{tube}} \cdot P_{\mathrm{G}} \cdot P_{\mathrm{T}} \cdot P_{\mathrm{D}}$$

where:

» P_{fin} = Particles fraction lost due to impaction on fin edges,

» P_{tube} = Particles fraction lost due to deposition on tube surface,

» P_{G} = Particles fraction lost due to gravitational settling,

» P_{T} = Particles fraction lost due to deposition by turbulence, and

» P_{D} = Particles fraction lost due to the due to Brownian motion.

Slide 7

BC2 is this length or diameter if we talk about fibrous fouling?
Bach, Christian, 6/29/2016

LU1 diameter
Lab User, 6/29/2016

BC3 The reader has no idea what the different P's are. Please add below the formula. You might need to split the slide up into two slides. A lot of text already
Bach, Christian, 6/29/2016

LU2 added
Lab User, 6/29/2016

Fouling Phenomenon

- Strong function of particle size but a weak function of air velocity and fin spacing.
- Dominating mechanisms by particle size:
  - » (0.01-1 µm) deposited by Brownian diffusion.
  - » (1-10 µm) deposited by impaction on fin edges.
  - » (>10 µm) deposited by air turbulence, impaction on tubes and gravitational settling.

Biofouling

- Two types of fouling commonly found in literature for air cooled heat exchangers:
  - » Biofouling, and
  - » Air dust deposition.
- Biofouling
  - » Biological matter in the air stream
  - » Microorganisms nourishes in prolonged presence of water on surface of heat exchangers.
- Effect of biofouling on the performance of the heat exchangers was studied by Pu *et al*. (2009).
  - » Results see next slide

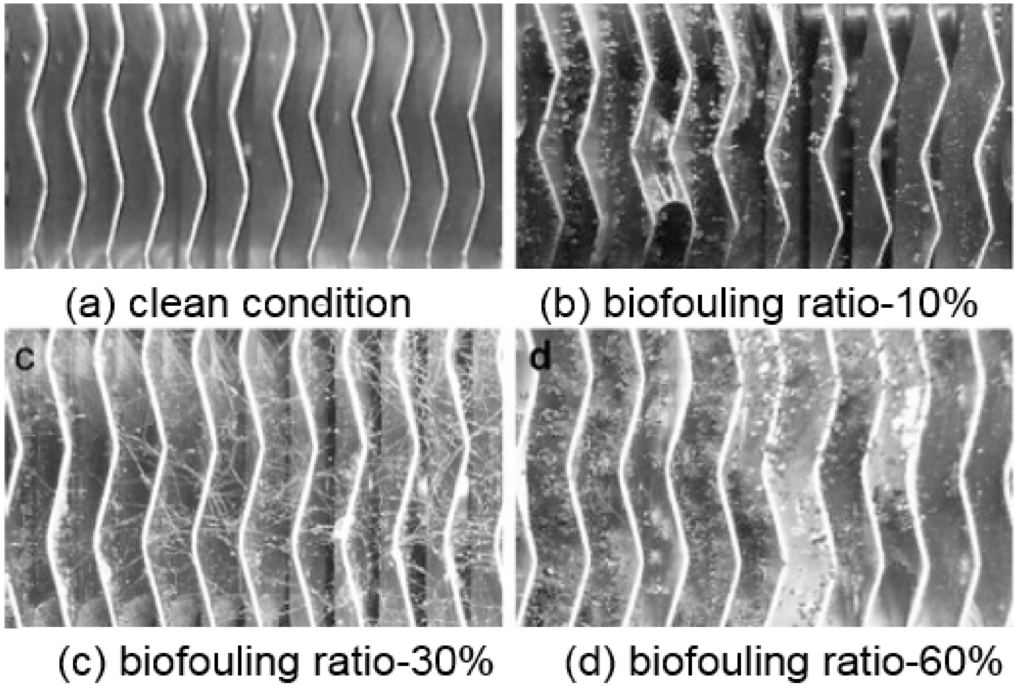
Slide 9

BC4 This contradicts some of your previou slides, including slide 5
Bach, Christian, 6/29/2016

LU4 biofouling-->biological fouling , and air dust deposition--> particulate fouling
Lab User, 6/29/2016

Biofouling

- Biofouling causes hydrophilic coating on heat exchanger surface to fail.
- For 2 m/s air velocity
  - » Heat transfer coefficient decreased by 7.2% and 15.9 % for a biofouled area ratio of 10% and 60 % respectively.
  - » Pressure drop increased by 43.1% for a biofouled area ratio of 60% .



Heat exchangers during biofouling test with Aspergillus niger (Pu et al. 2009)

Air Dust Deposition Fouling

- Various researchers studied the dust deposition fouling for different heat exchangers.

Source	Heat exchanger type	Dust type	Amount of injected dust	Heat exchanger face area
Ali & Ismail (2008)	Plate fin-and-tube	From used field installed evaporators	300 g	0.048 m^2
Ahn *et al.* (2003)	Fin and tube	Heat exchanger samples from field	Not applicable since field units were tested	No information given
Bell & Groll (2010)	Microchannel & Plate fin	ASHRAE standard dust & Arizona road test dust	300 g	0.2 m^2
Yang *et al.* (2007)	Wavy fin and Lanced fin	No dust (Strip of paper to simulate fouling)	Not Applicable	0.372 m^2
Pak *et al.* (2003)	Plate fin and Spine fin	ASHRAE standard dust	300 g	No information given
Qureshi & Zubair (2011)	Plate fin	Not applicable (model developed using EES)	Not applicable	No information given

- Air-side fouling depends on a number of factors on the heat exchanger (system) side and the air-side.

Air Dust Deposition Fouling

- In HVAC systems, fin & tube heat exchanger are extensively used for residential, commercial, and industrial applications.
- For the fin and tube exchangers, airside fouling is dependent on:
  - » Fin type,
  - » Number of tube rows,
  - » Heat exchanger type,
  - » Fin spacing,
  - » Refrigerant type, and
  - » Filters, if any.

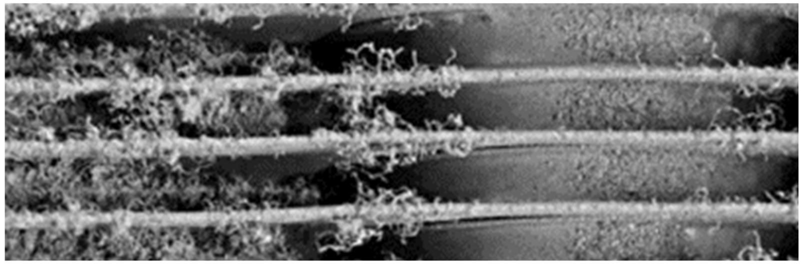
Slide 12

BC6 I think you already established this in the beginning, need to mention it here again?
Bach, Christian, 6/29/2016

LU5 emphasis on fin and tube exchangers, literature review is for fin and tube exchangers
Lab User, 6/29/2016

Air Dust Deposition Fouling

- Air dust fouling is more severe on the front face than the rear face [(Pak *et al.*, 2005) & (Ali & Ismail, 2008)].
- On the frontal face, dust accumulates on the leading edges



Front face of coil fouled with 600g of injected dust. (Bell et al., 2011)

- Pak *et al.* (2005) found that out of the total amount of dust injected, amount of dust accumulated on single row condenser was 30-50% and 60-67% on double row condenser.
  - » The relative increase in pressure drop was almost identical for double and single row condenser.

Slide 13

BC7 30-50% accumulated at front of HX? not clear...

Bach, Christian, 6/29/2016

Air Dust Deposition Fouling

- The performance of microchannel heat exchanger is more severely affected than plate & fin exchangers (Bell & Groll, 2010).
- Qureshi & Zubair (2011) conducted simulations with vapor compression refrigeration system model. BC8
- The percentage decrease in the *UA* value due to air-side fouling was varied from 0% (*clean*) to 50% for heat exchanger.
- 3 different cases were considered:
  - » Condenser only fouling,
  - » Evaporator only fouling,
  - » Combined evaporator and condenser fouling.

Slide 14

BC8 What model? The audience has no clue if this is a deposition model or a simple 4 component model with some factors for fouling
Bach, Christian, 6/29/2016

Air Dust Deposition Fouling

- Coefficient of performance (COP) of the condenser only fouling case was lower than evaporator only fouling.
- COP in the combined case was lower than other two cases.
- Yang *et al.* (2007) analyzed the cooling efficiency of packaged air conditioners equipped with filters for minimum efficiency reporting value (MERV) 4 to MERV 14.
  - » Energy efficiency ratio (EER) of the system for both clean and fouled case is reduced significantly by high-efficiency filters.

Air Dust Deposition Fouling

- Siegel *et al*. (2002) analyzed residential evaporator coil performance by presenting a fin and tube heat exchanger fouling model.
  - » The mass concentration distribution function m_c, is

$$m_{\mathrm{c}} = P_{\mathrm{d}}\,(1 - \eta_{\mathrm{f}} + \eta_{\mathrm{f}}\, b_{\mathrm{f}}) \cdot \eta_{\mathrm{c}} \cdot (1 - b_{\mathrm{c}}) \cdot m_{\mathrm{in}}$$

where:

- o P_{d} = Particles fraction not removed by deposition in the duct work,
- o η_{f} = Filter efficiency calculated using ASHRAE standard 52.2
- o b_{f} = Filter bypass
- o η_{c} = Coil deposition fraction, and
- o m_{in} = Indoor particle distribution function

Air Dust Deposition Fouling

- Fouling time, τ_{foul} is the time taken to double the pressure drop across the heat exchanger coil for a given air flow rate:

$$\tau_{foul} = \frac{M_{foul}}{Q\ M_c DC},$$

  - $Q =$ Air flow rate through the system
  - $DC =$ Duty cycle of the air handler fan
  - $\mathrm{M}_{foul} =$ Deposited mass for pressure drop of coil to double.

- M_c is the total mass distribution that deposits in the coil:

$$M_c = \int_{d_p} m_c \, \mathrm{d}d_p$$

  - d_p is the particle diameter and ranges from .01-100 µm.

Air Dust Deposition Fouling

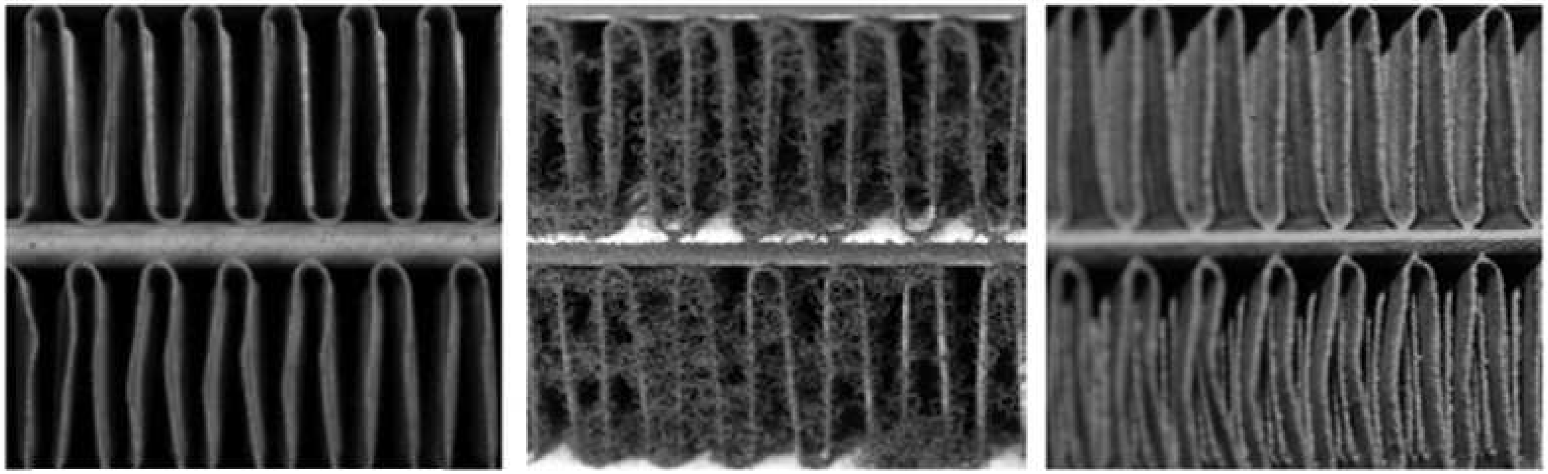
- Fouling time ratio is the ratio of fouling time of a particular case in comparison to the base case.
- Average fouling time for the base case was 7.6 years.

Fouling time ratios (Siegel et al. 2002)

			Fouling Time Ratio		
Variable	**Base Case**	**Going to**	**Median**	**GM**	**GSD**
Filter Efficiency	MERV 2	MERV 6	1.39	1.39	1.08
		MERV 12	10.04	6.89	2.79
Indoor Concentration	Urban	Rural	0.43	0.45	1.23
	Cycling	CA	0.31	0.30	1.09
	Dirty	Clean	1.85	1.70	1.45
Coil Efficiency	4.7 fin/cm	2.4 fin/cm	1.82	1.90	1.11
		7.1 fin/cm	0.71	0.70	1.05
Filter Bypass	10%	None	1.81	1.12	2.26
		25%	0.73	0.86	1.38
Duct Penetration	Typical	Simple	0.99	0.99	1.01
		Complex	1.02	1.02	1.01

Air Dust Deposition Fouling

- Bell & Groll (2010) investigated heat exchangers performance using two fouling agents:
  - » ASHRAE standard dust (ASHRAE standard 52.1), includes fibrous matter.
  - » Arizona road test dust (particles only) as limiting case for fouling in the areas with little fibrous matter.



(a) Clean condition

(b) Fouled with 135g of ASHRAE test dust

(c) Fouled with 500g of Arizona Road test dust

Air Dust Deposition Fouling

- Bell & Groll (2010) investigated the performance of heat exchangers using two different types of dust.
  - » The pressure drop for heat exchanger fouled with ASHRAE test standard dust was larger than Arizona test dust.
  - » Heat transfer reduced more in case of Arizona test dust due to its low thermal conductivity.
- Ali & Ismail (2008) used fouling material collected from evaporators that were put in their actual application.
  - » Sieve analysis was used to determine that particles ranged in size from 0.01 to 200 µm.
  - » The fouling rate was found to be a strong function of air velocity.
  - » COP increased with the increase in air velocity in both the clean and fouled cases.

Conclusion

- A literature review of fouling in heat exchangers focused on air conditioning applications is presented.
- Fouling is more severe on the front face as compared to the rear face.
- The impact of fouling in increasing pressure drop for constant air flowrate is greater than the decrease in heat transfer.
  - » Exception is particulate fouling with no fibrous matter
- Using high-efficiency filters before evaporators causes an increase in fouling time.
- Increase in COP with an increase in air velocity for both the fouled and clean cases.

References

- Ahn, Y.-C., Cho, J.-M., Shin, H.-S., Hwang, Y.-J., Lee, C.-G., Lee, J.-K., Kang, T.-W. (2003). An experimental study of the air-side particulate fouling in fin-and-tube heat exchangers of air conditioners. *Korean Journal of Chemical Engineering, 20(5).*
- Ali, A. H., & Ismail, I. M. (2008). Evaporator air-side fouling: effect on performance of room air conditioners and impact on indoor air quality. *HVAC&R Research, 14(2),* 209-219.
- Mostafa M. Awad (2011). Fouling of heat transfer surfaces, heat transfer - Theoretical analysis, experimental investigations and industrial systems, Prof. Aziz Belmiloudi (Ed.), ISBN: 978-953-307-226-5, *InTech*.
- Pak, B. C., Groll, E. A., & Braun, J. E. (2005). Impact of fouling and cleaning on plate fin and spine fin heat exchanger performance. *ASHRAE Transactions*, *111(1).*
- Siegel, J. A., & Nazaroff, W. W. (2003). Predicting particle deposition on HVAC heat exchangers. *Atmospheric Environment, 37*(39), 5587-5596.
- Sippola, M. R. (2002). Particle deposition in ventilation ducts. *Lawrence Berkeley National Laboratory*.
- Bell, I. H., & Groll, E. A. (2010). Experimental comparison of the impact of air-side particulate fouling on the thermo-hydraulic performance of microchannel and plate-fin heat exchangers. *International Refrigeration and Air Conditioning Conference*.

BC12

Slide 23

BC12 This looks like a picture from a website. Needs a citation! Suggest you follow my old example and just put in the first slide with fadng in a semi-transparent black surface in front of it.

Bach, Christian, 6/29/2016