CHEMICAL ENGINEERING TRANSACTIONS
VOL. 69, 2018

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.aidic.it/cet

Guest Editors: Elisabetta Brunazzi, Eva Sorensen

**ISBN** 978-88-95608-66-2; **ISSN** 2283-9216
DOI: 10.3303/CET1869136

# The GX Fiber Bed – A Novel Mist Eliminator with Improved Aerosol Removal Performances

Carlotta Del Ministro[a], Federica Bosio[b], Stefano Spreafico[b], Elisabetta Brunazzi[a]

[a]Department of Civil and Industrial Engineering, University of Pisa, Italy
[b]AWS Corporation srl, Italy
delministrocarlottaic@gmail.com

Undesired aerosol formation in gas–liquid contact devices like for instance absorbers, quench coolers, or condensers, causes severe complications in industrial processes. Gas-liquid coalescing filter media, normally called fiber beds or candles filters, have received great attention in a wide variety of industrial applications, being a removal technology with one of the highest achievable droplet removal efficiency for submicron particles. This work deals with a novel multi-layer fiber bed, the GX mist eliminator, developed by AWS Corporation srl with improved performances compared to the conventional single-layer fiber bed commercialized by the Company. The novel fiber bed was conceived by means of a developed design model that takes into account constructional and operating parameters. The model was validated by experiments carried out on a lab scale unit. The performances of the novel fiber bed were then validated by experiments carried out in a pilot plant installed on a production line with plasticizer oil mist. For the laboratory scale the same oil was used to measure the separation efficiency and the pressure drop.

## 1. Introduction

In gas–liquid contact devices aerosols (mist) can be formed by spontaneous condensation or desublimation in supersaturated gas-vapour mixtures, or chemical reaction. Conventional countermeasures such as water wash, wire-mesh (Brunazzi and Paglianti, 2001) and vane-type mist eliminators (Galletti et al., 2004) or axial-flow cyclones (Brunazzi et al. 2003), are not effective in removing aerosol based emissions because their submicron size allows the droplets to follow the gas flow (Khakharia et al. 2014). Therefore, gas-liquid coalescing filter media have received great attention in a wide variety of industrial applications (e.g. the removal of mists in absorption towers like in the sulphuric acid, phosphoric acid, hydrochloric acid units, SO2 gas sulfonation, ammonium nitrate neutralizers, and in the clean-up of gases, like dry and wet chlorine gas, and oil mist removal after rotary-sealed type compressors, in the textile fibers extrusion operations or in vacuum units from oil-sealed pumps). Candle filters consists of a cylindrical metal cage on whose external surface fibers are wound and held in position by another concentric cage. The filtering media is usually between 25 and 75 mm thick and is traversed radially by the gas stream, from inside to outside or vice versa. The trapped droplets coalesce, drain through the filter bed and the liquid collected is then drained out from the separator. Depending on the application, filtering media could be made of glass, polypropylene, polyester or ceramic fibers. Glass fibers, in particular, are available in two main categories: rope (the fiber is spun and sold in the form of cords) and mattress (the fibers are arranged randomly on a support and chemically bound to it). The aim of this study was to conceive and analyze the performance of a novel glass fiber bed separator, intended primarily for the removal of very fine mist droplets of less than 2 μm, with improved performances compared to the conventional single-layer fiber bed commercialized by the Company (AWS Corporation).

## 2. Lab scale tests and analysis of the results

### 2.1 Lab scale experimental loop

Experimental separation efficiencies, as a function of droplet size and gas velocity, and pressure drop across the separator were measured at atmospheric working conditions, using air and DOP (dioctyl phthalate) as

Please cite this article as: Del Ministro C., Bosio F., Spreafico S., Brunazzi E., 2018, The gx fiber bed - a novel mist eliminator with improved aerosol removal performances, Chemical Engineering Transactions, 69, 811-816 DOI: 10.3303/CET1869136

working fluids. Tests were carried out in the lab scale apparatus shown in Figure 2.1a, which is mainly made up of an aerosol generation circuit, an air carrier circuit and the separator. The aerosol is generated by a liquid nebulizer (Palas, model AGF10). The air carrier circuit consists of the pipe upstream and the pipe downstream the separator and the fan, which is controlled with an inverter and keeps the two phase flow transport circuit in suction. Pressure drop across the filter are measured by means of a U-shaped pressure gauge connected to two pressure taps present on the tank. A scattered light spectrometer (Palas, model Welas® 2000) is used to measure the diameter distribution of DOP droplets (dimensions range 0.15 - 10 µm) dispersed in the air stream. The instrument is interfaced with a software (PDControl), which analyzes the data and supplies the size distributions of the droplets (see Figure 2.1b). Acquisitions were carried out both upstream and downstream the separator. The nebulizer pressure was set in order to obtain a mist concentration of 35 mg/m$^3$ in the inlet gas stream. The combined effects of direct interception, inertial impact, and Brownian diffusion determine the typical V-shape of the removal efficiency curve versus droplet diameters shown in Figure 2.1c. This feature is due to the fact that larger droplets are subject mainly to direct interception and inertial impact, while diffusion is dominant for smaller droplets. The lower point of the efficiency curve, i.e. the Most Penetrating Particle Size (MPPS), varied typically in the range between 0.25 and 0.4 µm for the tested separators.

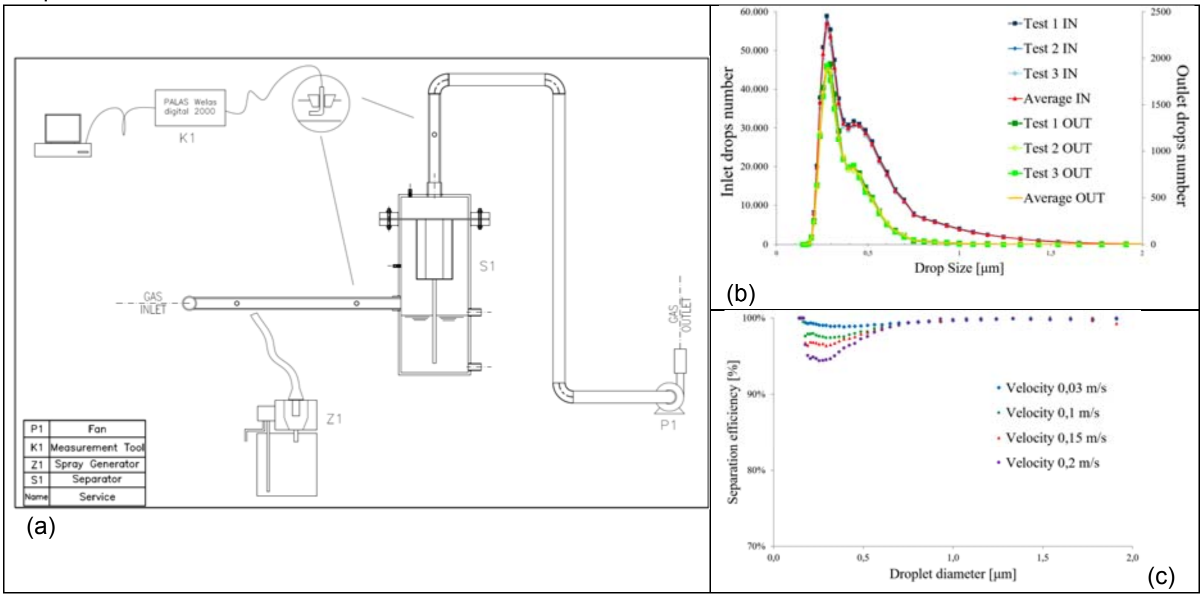


*Figure 2.1: Lab scale experimental loop (a), examples of measured inlet and outlet drop size distributions (b) and experimental efficiency curves (c)*

### 2.2 The tested single-layer candles and results

Various candle-types were tested in the lab scale experimental loop in order to investigate the dependence of both the separation efficiency and pressure drop on the filtration velocity and the most important constructional parameters, i.e.: wrapping mode (parallel or crossed), glass fibers size, packing density, filter media thickness. To this scope, candle E, currently commercialized by the company was taken as reference and one constructional parameter at a time was changed, thus obtaining four new candles named E1, F, G, H, each with just one parameter changed with respect to candle E. In addition, a fifth candle, named L, was constructed by using mattress instead of rope fibers. The main characteristics of the five candles are listed in Table 1.

*Table 1: Main constructional parameters of candles E , E1, F, G, H and L*

| Candle | Glass fiber diameter [µm] | Glass fiber type and Wrapping mode | Packing density [kg/m$^3$] | Bed Thickness [mm] |
|---|---|---|---|---|
| E | 8 | Rope, Parallel | 175 ÷ 185 | 50 |
| E1 | 10.5 | Rope, Parallel | 175 ÷ 185 | 50 |
| F | 8 | Rope, Crossed | 175 ÷ 185 | 50 |
| G | 8 | Rope, Parallel | 130 ÷ 145 | 50 |
| H | 8 | Rope, Parallel | 175 ÷ 185 | 25 |
| L | < 5 | Mattress, Random | 50 ÷ 65 | 50 |

Efficiency tests and pressure drop measurements were carried out for all the five candles at four different gas filtration velocities: 0.03, 0.1, 0.15 and 0.2 m/s. The filtration velocity is referred to the logarithmic mean area calculated from the filter bed inner and outer radius. Figure 2.2a compares the experimental separation efficiency versus drop diameter obtained for example with a filtration velocity of 0.1 m/s, while the experimental pressure drop versus the gas filtration velocity are shown in Figure 2.2b.

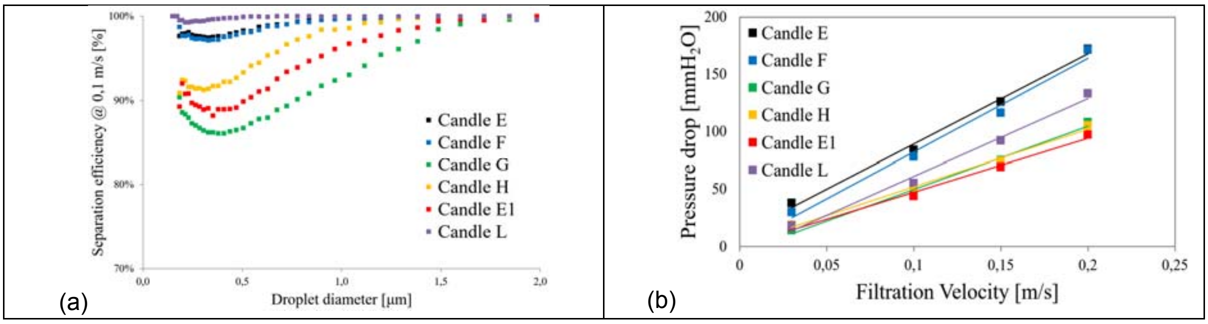


*Figure 2.2: Comparison between reference Candle E and the new single-layer filters (E1, F, G, H and L): experimental efficiency curves (a), experimental pressure drops (b)*

From the results, the following main conclusions can be drawn: 1) the wrapping mode does not influence efficiency and pressure drop; 2) a fiber glass diameter increase from 8 µm to 10.5 µm causes an efficiency reduction from 97% to 89% in correspondence of the MPPS diameter, with a pressure drop reduction of about 50%; 3) a density reduction of about 25% causes an efficiency reduction from 97% to 86% in correspondence of the MPPS diameter; 4) filter media with 25mm thickness show a good efficiency but with a pressure drop reduction of about 50%; 5) the mattress leads to an increase of efficiency with a significant pressure drop reduction similar to the candle E1, but mattress could entail drainage or clogging problems due to the very small fibers diameter.

**2.3 Model development and validation**

The filter element is composed of millions of fibers, resulting in very high separation efficiencies through their cumulative effect. By starting from the Brown's model (Brown, 1993), and considering that, due to the cylindrical geometry, the gas velocity inside the filter varies significantly along the radial coordinate (between -28% and +44% compared to the average velocity for the tested candles), the fiber bed separation efficiency can be expressed as a function of the single fiber separation efficiency and the filter geometry with the integral along the filtration bed radius. The single fiber efficiency takes into account the contribution of different separation mechanisms: inertial impact, direct interception and Brownian diffusion. There are several models in the literature for the prediction of the three separation mechanisms. The involved equations depend on many physical quantities; a thorough investigation of the efficiency and pressure drop trends with the different constructional parameters has been performed in this study. Analysis of the obtained experimental results allowed selecting the correlations, among the available ones in literature, most suited to predict the efficiency and pressure drop for this type of filters. Details of the model and the chosen correlations are not shown here for brevity, but can be found in Del Ministro (2014).

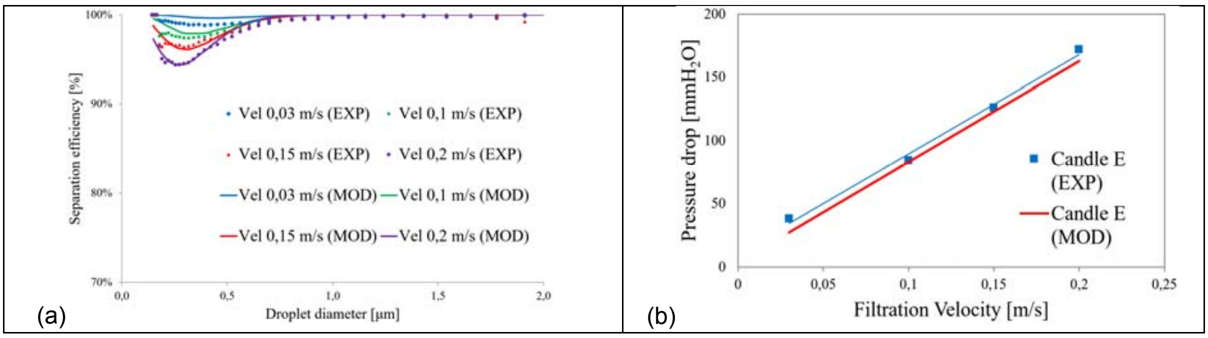


*Figure 2.3: Candle E theoretical and experimental efficiency curves (a) and pressure drops (b)*

Figure 2.3 shows for example a comparison of measured and computed separation efficiency, versus particle diameter, and pressure drop, versus filtration velocity, for the candle E. Similar trends were obtained with all the tested candles, showing that the model is able to take into account satisfactorily the effect of the constructional parameters and operating conditions on the overall performances.

### 2.4 The new multi-layer fiber beds

Once validated, the theoretical model was used to conceive novel multi-layer candles, which were then constructed and tested experimentally. Indeed, the combination of glass fiber layers with different characteristics could exploit the advantages of each layer. The multi-layer candles listed in Table 4, with overall filter bed thickness of 50 mm, were analyzed. Figure 2.4 shows the experimental results obtained with candles I, J, K compared with those obtained with candle E.

*Table 4: Multi-layer candles: layer types in order from the gas inlet to the gas outlet*

| Candle type | 1st layer | 2nd layer | 3rd layer | 4th layer | Packing density [kg/m$^3$] |
|---|---|---|---|---|---|
| I | E1 | E | | | 175 ÷ 185 |
| J | E | E1 | | | 175 ÷ 185 |
| K | E1 | E | E1 | | 175 ÷ 185 |
| M | E1 | E | L | E1 | 140 ÷ 150 |
| GX | E1 | E | L | E1 | 140 ÷ 150 |

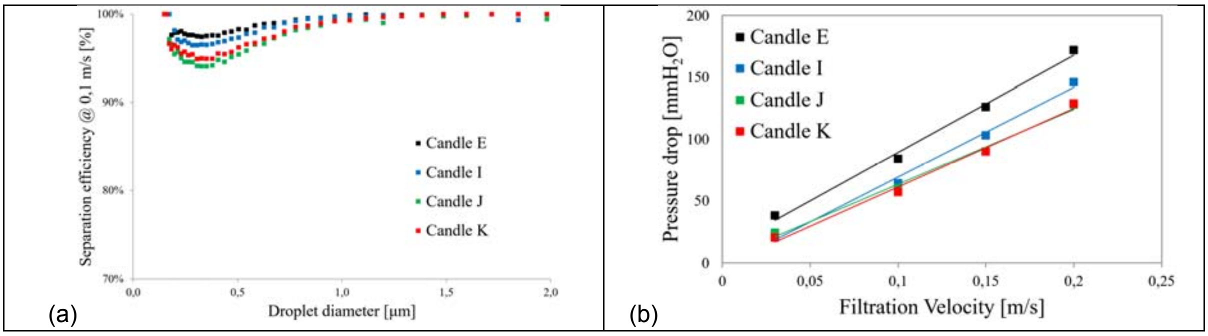


*Figure 2.4: Comparison between candle E and new filters (I, J and K) of experimental efficiency curves (a) and experimental pressure drop (b)*

The combination of different glass fiber layers lead to a pressure drop decrease of about 25%, with a reduction of the efficiency value in correspondence of the MPPS diameter from 97.5% to 96.5% (candle I), 95% (candle K) and 94% (candle J).

Figure 2.5 shows the experimental results obtained with the multi-layers candles M and GX. The introduction of an additional layer of fiber mattress leads to approximately similar separation efficiencies compared to candle E but with reduced pressure drop. Candle GX in particular was identified as the most promising and therefore, based on it, a prototype was constructed and tested in the pilot scale plant. The prototype performances were monitored over a long period (10 months), thus testing its drainage capability and quantifying the effects of bed saturation on the performances. Bed saturation in fact could cause an increase of fibers diameter and a reduction of candle void fraction; these two effects could increase the pressure drops and reduce the efficiency but their real behaviors and entities are difficult to estimate basing on the current theoretical models available in literature. The candle testing on prototype scale could thus help identifying the actual consequences of the bed saturation in order to implement this effect in the developed model.

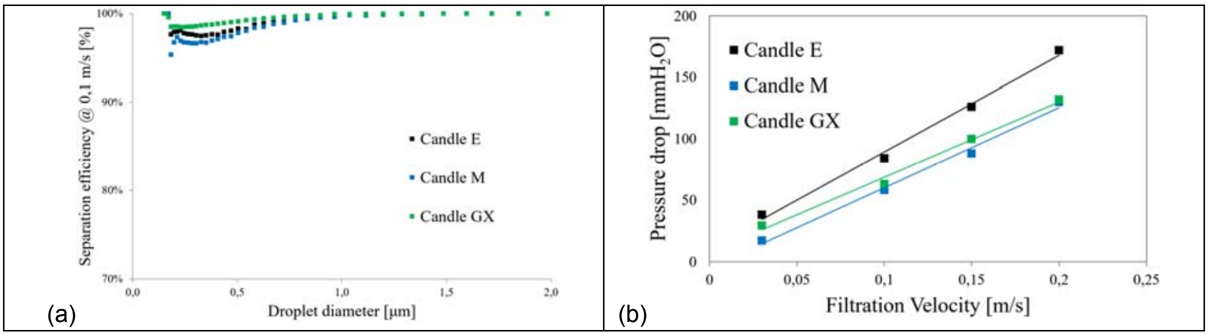


*Figure 2.5: Comparison between candle E and new filters (M, GX) experimental efficiency curves (a), and pressure drop (b)*

## 3. Pilot plant configuration and results

In order to validate the performances of candles tested on laboratory scale, a pilot plant, with three candle elements (with outer diameter of 230 mm and height 600 mm), was realized and installed on a production line with plasticizer oil mist. The validation of a prototype consists in a functional check in real working conditions, which is performed by recording the pressure drop on the candles and measuring the mist concentration, both at the separator inlet and outlet, to obtain the separation efficiency over time. The limit of oil mist concentration at the outlet to validate a prototype is < 7 mg/m$^3$. This value correspond to a visible plume at the stack. The filters taken under validation are the standard AWS filter (i.e. candle E) taken as reference and the candle with the most promising results obtained in the lab scale tests (i.e. candle GX). The industrial pilot plant configuration is show in Fig. 3.1a and consists basically of the following parts: inlet tube with three sampling ports, candle vessel with pressure drop indicator and three candles installed, manual flow regulation valve, outlet tube with three sampling ports, main fan, bypass line with a valve (normally closed), oil drain tube.

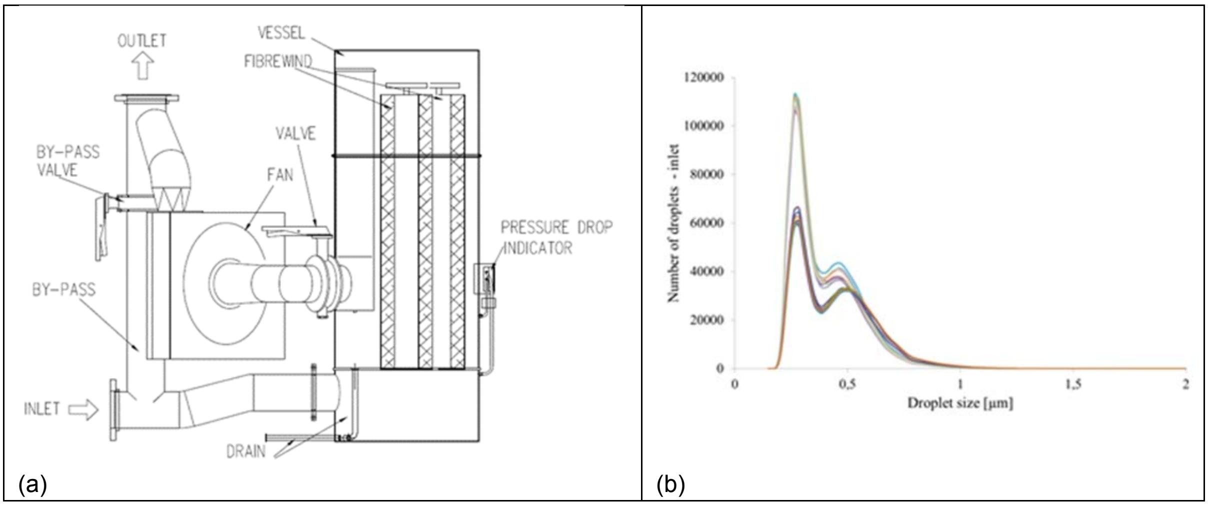


*Figure 3.1: Pilot plant configuration (a) and typical droplet size distribution of the aerosol measured at the filter inlet with varying oil mist concentrations (b)*

The oil mist concentration in the inlet gas strongly depends on the productions and varies between 50 mg/m$^3$ and 100 mg/m$^3$, however the oil mist droplet distribution is quite comparable, as show in Figure 3.1b. Tests on the pilot plant were carried out with the same instrumentation and methods used for the laboratory tests, described before.

Figure 3.2a shows the experimental separation efficiency versus drop diameter obtained for example with a filtration velocity of 0.1 m/s over a time period of about 10 months, while pressure drop at different filtration velocities measured over the same time period are shown in Figure 3.2b. As expected, the decrease of bed void fraction which results from an increased accumulation of the collected liquid, causes an increase of the pressure drop over the time and a decrease of the separation efficiencies of the submicron droplets.

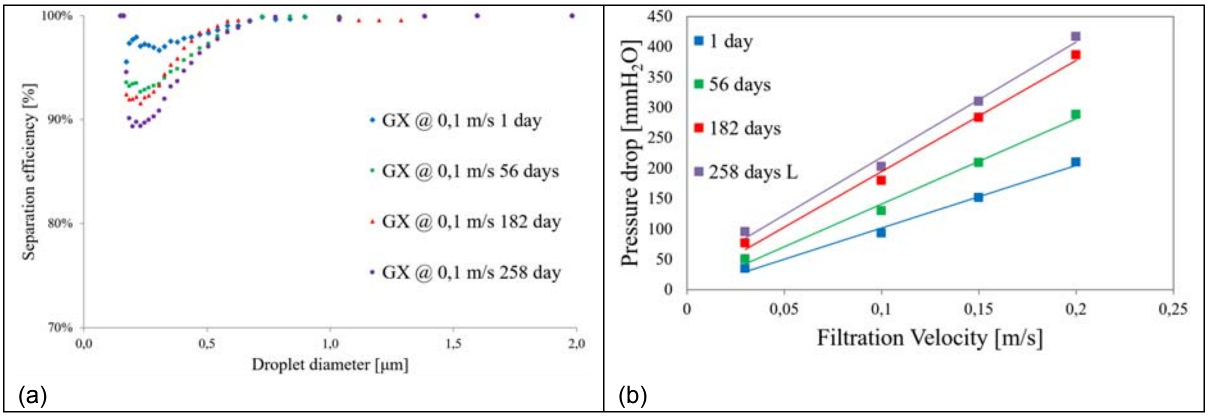


*Figure 3.2: Candle GX performances over time: separation efficiency at 0.1 m/s (a) and pressure drop at different filtration velocities (b)*

A performance comparison between the candles GX and E (also tested on the pilot scale plant) is shown in Figure 3.3. Separation efficiency versus droplet diameter (Figure 3.3a) at a 0.1 m/s filtration velocity, and pressure drop versus filtration velocity (Figure 3.3b) are shown for the two types of candles. After 1 month of operation, Candle GX shows about 25% lower pressured drop compared to the standard candle, while after about 2 months the separation efficiency is comparable to that of the standard candle measured after 1 month of operation. Furthermore, during the whole 258 days, the concentration of the mist at the outlet of the GX candle was always below the imposed limit.

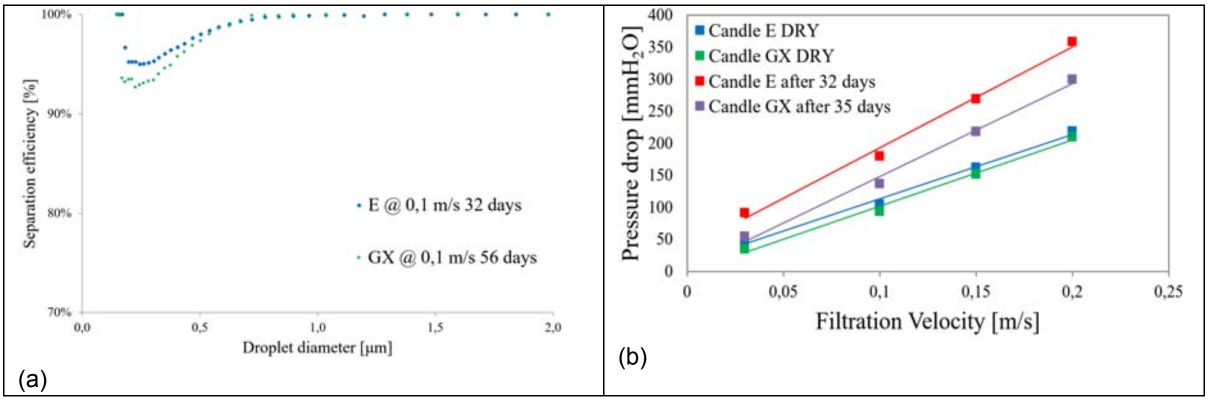


*Figure 3.3: Efficiency (a) and pressure drop (b) comparison between Candle GX and reference candle E.*

## 4. Conclusions

The aim of this study was to understand the effects of structural and operating parameters on the filtering candle efficiency and pressure drops, in order to develop an innovative candle with improved performance (i.e. increased efficiency with the same pressure drops or reduced pressure drops keeping the same efficiency), through a thorough study of the theoretical models available in literature and a validation of them with experiments in a lab scale unit. The introduction of glass fibers in mattress, in addition to rope fibers, led to a new candle, named GX, with approximately similar separation efficiencies compared to the standard candle E but with reduced pressure drops. During the life time of the candles, the removed liquid fills the filter up to the fully saturation of the filtering bed, when rate of drainage equals the rate of collection. The bed saturation could decrease the filter performances but its real effect is difficult to estimate basing on the theoretical models available in literature. For this reason, the candle GX was tested on an pilot plant installed on a production line and its performances were monitored over a long period (10 months). The results have shown that, as expected, the bed saturation reduces the efficiency, but compatibly with the environmental limit in the relevant applications. The separation efficiency is ~99.9% for all droplets with dimension larger than 3 μm and higher than 80% for all droplets smaller than 3 μm; in the latter range, the efficiency is strongly influenced by the filtration velocity. Also the pressure drops increase with time, but candle GX shows about 30% lower pressure drop compared to the reference candle E.

### References

Brown, R., 1993, Air filtration: an integrated approach to the theory and application of fibrous filters, Pergamon Press, Oxford, UK.

Brunazzi, E., Paglianti A., 2001, Conventional and complex knitted mesh mist eliminators. Chemical Engineering & Technology, 24, 1199-1204.

Brunazzi, E., Paglianti, A., Talamelli, A., 2003, Simplified design of axial-flow cyclone mist eliminators, AIChE J., 49, 41–51.

Galletti, C., Brunazzi, E., Tognotti, L., 2008, A numerical model for gas flow and droplet motion in wave-plate mist eliminators with drainage channels, Chemical Engineering Science, 63, 5639-5652.

Del Ministro, C., 2014, Experimental and modelling study of gas-liquid separators for submicron droplets (in Italian), M.Sc. Thesis, University of Pisa, Pisa, Italy.

Khakharia, P., Kvamsdal, H.M., da Silva, E.F., Vlugt, T.J.H., Goetheer, E., 2014, Field study of a Brownian demister unit to reduce aerosol based emission from a post combustion CO2 capture plant, Int. J. Greenhouse Gas Control 28, 57–64.