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# New material for the wire mesh demister

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ABSTRACT

An experimental investigation was made on the impact of various parameters on the dry pressure drop of wire mesh demister using three different materials of construction. The materials tested are the date palm fiber, industrial wire stainless steel 16 L, and *Luffa aegyptiaca* fiber. This study is limited to the measurement of the dry pressure drop using air as operating fluid. The dry pressure drop in the demister pad increases with air velocity and is inversely related to the wire size and the pad porosity. At constant air velocity, wire diameter, and pad porosity, the dry pressure for the date palm fiber is the minimum one followed by the *L. aegyptiaca*. The maximum dry pressure drop is observed when we used the stainless steel wire. Collected data are used to develop three empirical correlations for the dry pressure drop for the materials used.

*Keywords:* Mist eliminator; Wire mesh; Dry pressure drop; Date palm fiber; *Luffa aegyptiaca*; Thermal desalination

## 1. Introduction

Arab Gulf States suffer heavily from inadequate access to safe and high quality water. The Saudi Arabia is the largest area in the world without a single river.

It depends on seawater desalination for about 60% of its water supply. Most of the desalinated water in the Gulf is produced by the multi stage flash (MSF) and multiple effect evaporation (MEE) processes. These processes were introduced in the late 1950s and since that time, they have proved to be the most suitable technologies in the Gulf States. A detailed description of these techniques is given in [1–4]. The mist eliminator is one of the most important components in the thermal desalination units. The main function of the mist eliminators is the capture of the water droplets, which may be entrained with the boiled or/and flashed-off vapor. This is necessary to avoid the reduction of distilled water quality and the formation of scale on the external surface of the condenser tubes. The last effect is very harmful because it reduces the heat transfer coefficient, increases the pressure drop, and enhances the corrosion of the tube material. The most widely used type of mist eliminator in the thermal desalination units is the wire mesh mist eliminator. Wire mesh demisters are used for gas/liquid separation when the ratio of entrained droplets is relatively small. It is a simple highly porous blanket of metal or plastic. As generally used, it consists of a bed, usually 100–200-mm deep, of fine diameter wires interlocked by a knitting to form a wire mesh pad with a high free volume, usually between

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97 and 99%. The core advantages of wire mesh mist eliminators are low pressure drop, high separation efficiency, reasonable capital cost, minimum flooding tendency, high capacity, and small size. The performance of wire mesh eliminators depends on many design variables such as supporting grids, gas phase velocity, wire diameter, packing density, pad thickness, and material of construction.

The separation process in the wire mesh mist eliminator includes three sequences steps: (1) inertial impaction which occurs when the velocity and size of the droplet is sufficiently high. Direct interception takes place when the distance from the target is less than one-half of the droplet diameter, the particle may then be collected, (2) the amalgamations of the droplets impinging on the surface of the wires, and (3) droplets detach from the pad and drain back in the form of large droplets.

Classically, the demister is made of special materials to withstand the harsh operating condition in desalination units. These materials of construction include; stainless steel, nickel-based alloys, titanium, aluminum, copper, polypropylene and fluor plastics. Recently, three new alloys have been made available in wire form, which routinely provide three to five times the service lives of the traditional materials [5]. These are Lewmet 66, SX, and Saramet.

In the current study, the performance of wire mesh mist eliminator made of date palm fiber is investigated experimentally. The obtained data are compared with the data of industrial wire mesh demister made of stainless steel 16 L and *Luffa aegyptiaca* fiber. This study is limited to the measurement of the dry pressure drop using air as operating fluid.

The advantages of using such natural material as a material of construction in thermal desalination units are:

(1) Very cheap and available in a massive amounts in the Kingdom of Saudi Arabia and other Gulf States.
(2) Light in weight which decreases the mechanical structure of the flashing stages.
(3) Maintenance free, because it can be replaced with new fiber at nearly free of cost.
(4) Inert and can resist any chemical attack.
(5) Can be easily shaped to any configuration.
(6) It is naturally degradable with minimum impact on the environment.

To the best of our knowledge, this is the first time to propose and evaluate the use of date palm fiber and *L. aegyptiaca* as materials of construction for demisters in thermal desalination units.

The open literatures available deliberating the performance of wire mesh pads are relatively limited. They can be subdivided into theoretical simulation and experimental works. Examples of the first group include the study of Janajreh et al. [6]. They simulated the flow of water vapor in flashing chamber and evaluated the pressure drop in the demister. They considered the vapor velocity, the dimension of the demister, the pad porosity, and wire thickness. The obtained pressure drop was found to be within a reasonable agreement with the published literature data. Zhao et al. [7] conducted a numerical simulation of demister vanes with various geometries and operating conditions. The model showed that the separation efficiency depends on gas velocity, vane height and to high extent on the vane turning angles. Rahimi and Abbaspour [8] predicated the pressure drop in a mist pad by using numerical simulation. The pressure drop was estimated as a function of vapor velocity (1–7 m/s), packing density (200 kg/m$^3$), pad thickness (200 mm), wire diameter (0.31 mm), and distance between mesh wires of (5 mm). The data showed that the predicted pressure drop is deviated by about 14–21% from the experimental data of El-Dessouky et al. [9]. Feord et al. [10] proposed a mathematical model to specify the outlet concentration and droplet size distribution for knitted mesh mist pad. The model predicted variations in performance and the decrease in the separation efficiency with decreasing both the droplet size in the feed mixture and the gas velocity. Also, they predicted quantitatively the flooding velocity and compared it with the experimental results measured. The model offers the prospect of optimizing the pad construction to maximize the separation efficiency at a target pressure drop or designing to a maximum pressure drop. Kouhikamali [11] examined numerically the dependence of the separation efficiency and the pressure drop of the wire mesh mist eliminator on the geometry and operating condition. The considered parameters are the vapor velocity, (1–20 m/s), packing density (100–250 kg/m$^3$), demister thickness (300–200 cm), wire diameter (0.1–0.3 mm), and diameter of captured droplets (1–3 mm). The results showed that the increase in separation efficiency with increasing the diameter of water droplets, vapor velocity, packing thickness, and density while increasing wire diameter decreases the performance.

It is worth mentioning that the main drawback of the theoretical models developed by different authors is the need for complete information on the entrainment level and the droplet size spectra upstream and downstream of the demister pads. This type of data is not always available in practical units. Measuring droplet size distribution, especially in the small size range, is quite difficult, costly, and prone to inaccuracies. It is usually practical to develop such data only in the laboratory or pilot plant. Moreover, in many realistic cases the droplet spectrum is highly dynamic and undergoes rapid changes due to any disturbance in the evaporation process. Also, Phillips and Deakin [12] showed that a lot of uncertainties arise in the theoretical evaluation of demister efficiency and pressure drops.

On other hand, the experimental data available considering the pressure drop in the wire mesh pads are very limited. El-Dessouky et al. [9] conducted a comprehensive experimental study to measure the performance of wire mesh mist eliminator made of stainless steel 316 L wires. The demister performance was evaluated by droplet separation efficiency, vapor pressure drop of wet and dry demister, and flooding and loading velocities. These variables were measured as a function of vapor velocity (0.98–7.5 m/s), packing density (80.317–208.16 kg/m$^3$), pad thickness (100–200 cm), wire diameter (0.2–0.32 mm), and diameter of captured droplets (1–5 mm). All the measurement results lie in ranges where, in practice, the wire mesh mist eliminator predominates. The experimental results indicated that the separation efficiency increases with both the maximum diameter of captured water droplets and the vapor velocity and with the reduction of wire diameter. The pressure drop for the dry demister is relatively low and depends mainly on the vapor velocity, wire diameter, and the bed porosity. The pressure drop increases linearly up to the loading point; thereafter, the rate of increase is larger. Beyond the flooding point, the increase rate is significant even for the slightest rise in the vapor velocity. The flooding velocity diminishes with the beef up of the packing density and with the decrease of the wire diameter. Three empirical correlations were developed as a function of the design and operating parameters for the separation efficiency, pressure drop for the wet demister in the loading range, and the flooding and loading velocities. These correlations are sufficiently accurate for practical calculations and demister design. Svendsen and Helsør [13] predicted the dry pressure drop for seven different wire mesh demisters experimentally. The operating fluids used were air and a mixture of nitrogen and natural gas. They cited that the dry pressure drop can be calculated only based on the mesh porosity in regions where form drag dominates. Abdullah et al. [14] studied experimentally the effects of design parameters on pressure drop across the wire mesh mist eliminators in 15-cm bubble column. The pressure drop across the demister pad was evaluated as a function of wide ranges of operating and design parameters. They showed that the dry pressure drop is nearly nil. The wet pressure drop was found to increase with the demister specific surface area, packing density, and superficial gas velocity. In contrast, it was found that it goes up with decreasing the demister void fraction and wire diameter. The pressure drop is correlated empirically as a function of the studied parameters. Bradie and Dickson [15] discussed the factors governing the performance of wire mesh demister, in particular with their application to entrainment removal in pool-boiling systems. They derived the separation efficiency of the demister pad from the collection efficiency for a single wire. This efficiency is used to determine the minimum vapor velocity as a function of droplet size. Correlations developed for the single and two-phase (dry and wet) pressure drop through the demister together with empirical formula relating the flooding point to the vapor and liquid velocities. They measured the pressure drop and flooding conditions for a series of demisters installed in a small 140-mm diameter wind tunnel. The tested demisters included the layered and spiral-wound configurations. All the experimental results were taken for air–water at atmospheric pressure and ambient temperature. No attempt has been made to use fluids with different properties or to operate the system at other conditions. Buerkholz [16], reported that, in order to prevent any re-entrainment of the water droplets captured in the wire mesh pad, the gas phase velocity should be limited to 4–5 m/s. Additionally, he presented experimental data for the flooding load, the corresponding increase in pressure drop, and the fractional separation efficiency.

The following conclusions can be drawn from the previous discussion:

(1) To the best of our knowledge, no one tested or suggested the use of date palm fiber and compared with other materials of construction for demister in thermal desalination units.
(2) The research on performance evaluation of the wire mesh mist eliminators under operating conditions similar to that dominating in evaporators, especially in thermal desalination systems, is still in an immature state.
(3) The available theoretical models devoted to the performance of the wire mesh mist eliminators are not adequate for implementing to the desalination industrial units.
(4) The pressure drop in wire mesh demister is relatively small.

The objective of this study is to measure experimentally the dry pressure of a wire mesh demister using date palm fiber. The pressure drop was measured as a function of gas phase velocity, wire diameter, and mesh porosity. All the measured data lie in a range where, in practice, the wire mesh mist eliminator predominates. The obtained data is compared with industrial wire mesh made of stainless steel 316 L and *L. aegyptiaca*.

## 2. Experimental work

The experimental apparatus used in obtaining the dry pressure drop for the three wire mesh demisters at different air velocity, bed porosity, and wire diameter is pictured in Fig. 1. The unit consists of Plexiglas column (1), demister pad (2), water accumulation tank (3), small capacity water tank (4), air compressor (5), and the instrumentation. The unit was prepared to study the dry and the wet pressure drop and the entrainment separation efficiency. However, this study is limited to measure the dry pressure drop. The Plexiglas column has an outer diameter of 50 mm and inside diameter of 40 mm. The Plexiglas enables the visual observation. It has three sections with different lengths. All connections are connected by flanges and rubber packing. The demister pad section is 200 mm in length; the upstream and downstream sections have heights of 400 and 300 mm, respectively. The mesh pads were fixed in the column in a vertical position which represents the layout in the thermal desalination units. There is a supporting grid at the bottom of demister pad section. The void in this supporting grid is about 95.6% which is necessary to minimize its effect on the pressure drop. The demister pad was held at the required height by fixing the bottom support grid to the ring and beam. The mesh pad was sized to be 3 mm larger than the column inside diameter to provide a snug fit. There is a fine grid with different opening sizes fitted at the lower part of the downstream section. The size of these openings can be changed from 1 to 3.5 mm. This net is used to control the size and the number of the entrained liquid droplets. All parts are fitted with many connections for sampling, temperature measurements, and gauging the absolute pressure and pressure drop across the

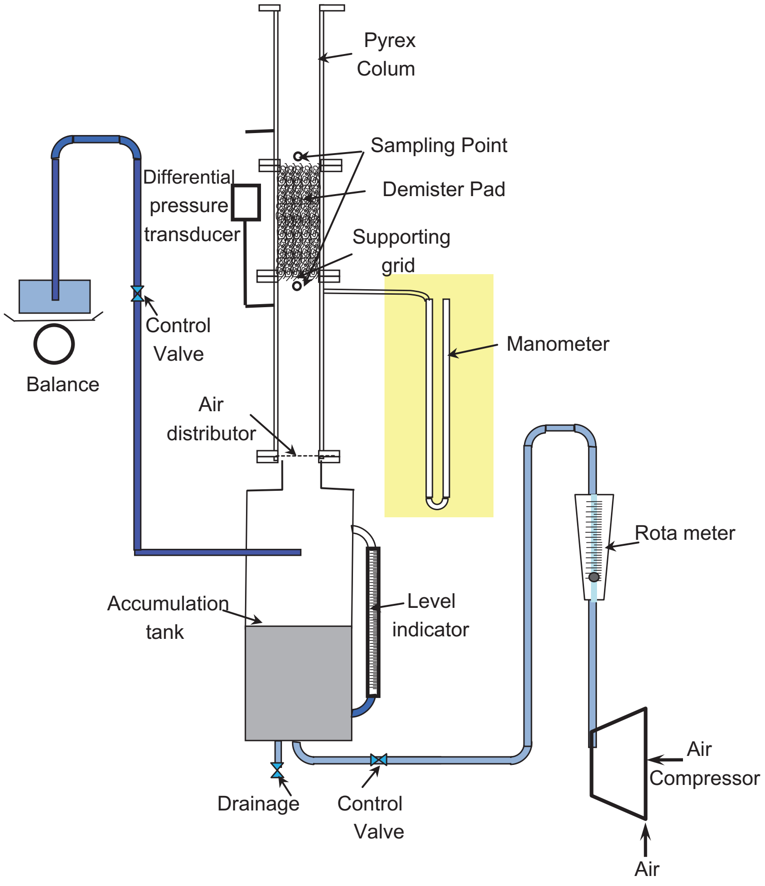


Fig. 1. The experimental set-up.

demister pad. The water tank is made of stainless steel with 200-mm diameter and 350-mm height. The tank is connected to the air supply line, water line, and drainage pipe. All connections are galvanized steel with 12.7 mm outside diameter. The water feed pipe is fitted with a nozzle of defined diameter to adjust the size of water droplet diameter. The tank is fitted with a side glass which can be used as a liquid level indicator. The power of the air compressor is 1.1 HP and it can supply an air flow rate of 14.5 $m^3/min$. All connections are sealed very well to the tank by a stocky layer of silicon rubber to minimize the air leakage which may affect the collected data. The velocity meter type TESTO 435–1 was used to measure the air velocity. Its accuracy is 5% of the full reading. The absolute pressure upstream the pad was measured with pressure transducer type Omega pressure data logger with LCD display-OM-CP-PR2000. Its accuracy is 2% of the full scale. Testo 6321 differential pressure transmitter model A08 was used to measure the pressure drop across the demister pad. Its accuracy is 1.2% of measuring range. Also, the same absolute pressure was measured with U-tube manometer filled by water. A glass tube was used to measure the liquid level inside the tank. All experiments were conducted at 1 bar with air as operating fluid. The experimental measurements were taken at steady-state conditions. In a typical run, the manometer readings were adjusted to zero values. The air valve was opened and the air is admitted into the water accumulation tank. The mass flow rate of air was controlled to achieve the air velocity inside the column, which ranges from 0.4 to 13 m/s. Data were recorded for each run after steady-state conditions had been maintained for at least 10 min. The results were accepted only when the difference in dry pressure drop recorded by the differential pressure transducer and the absolute pressure and the manometer reading was less than 5%. The porosity of the bed was measured before and after each experimental run to check any possible compaction as a result of pressure drop.

Three different materials were used as materials of construction for the wire mesh mist eliminator. These are: stainless steel 316 L, date palm fiber and *L. aegyptiaca*. Table 1 displays the physical and design data for the three wires. Table 2 spectacles the chemical composition for the three wires. Also, Fig. 2 represents the photos and the images of the electronic scanning microscope for the three types of wires used in constructing of mesh mist eliminator. The metallic wire is obtained from industrial demister used in Al-Jubail MSF plants. The demisters were made from several layers. The appropriate number of layers is chosen to give the desired pad height, porosity, and density.

Demisters are usually specified by means of their surface area ($A_s$), packing density ($\rho_{p)}$, and porosity ($\varepsilon$).

The specific area is defined as the surface area of the mesh divided by the total unit volume and given by:

$$A_s = \frac{\text{Surface area of wires}}{\text{Volume of demister}} = \frac{4 \times (1-\varepsilon)}{d_w} \tag{1}$$

The weight of the mesh material, $m_{\text{mesh}}$ exclusive of the support, was measured and the density of the mesh calculated by:

$$\rho_p = \frac{\text{Mass of wire}}{\text{Volume of demister}} = \frac{m_{\text{mesh}}}{\frac{\pi}{4} d_w^2 h'} \tag{2}$$

The porosity was then calculated using:

$$\varepsilon = 1 - \frac{\text{Volume occupied by wire}}{\text{Volume of demister}} = 1 - \frac{\frac{m_{\text{mesh}}}{\rho_{\text{material}}}}{\frac{\pi}{4} d_w^2 h'} \tag{3}$$

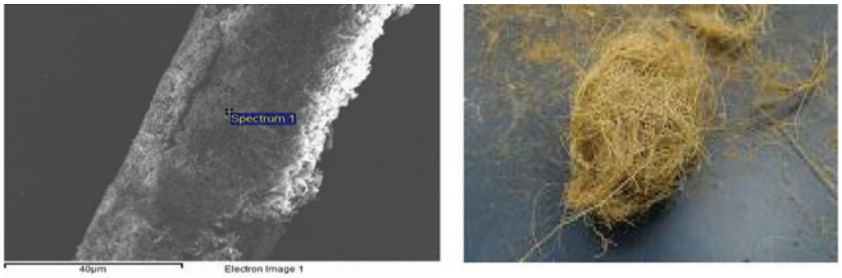
where $A_s$ is the specific surface area, $m^{-1}$; $d_w$ is the wire diameter, m; $h$ is the pad height, m; $m_{\text{mesh}}$ is the mass of the mesh pad, kg; $\rho_p$ is the pad density, $kg/m^3$; $\varepsilon$ is the demister porosity, dimensionless.

Table 1
Properties of the three wires used

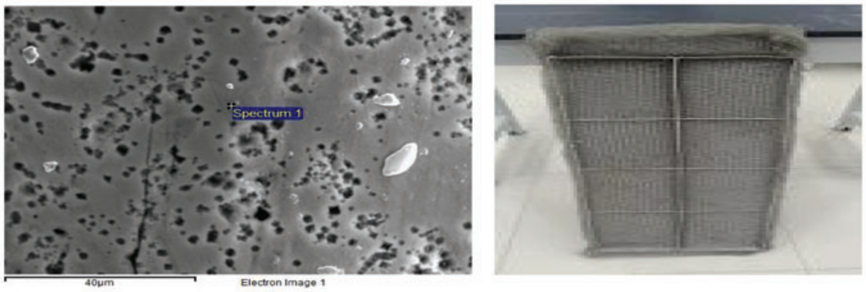
| Material | Density, $\rho_{\text{material}}$ ($kg/m^3$) | Wire diameter, $d_w$ (mm) | Porosity, $\varepsilon$ | Tensile stress, $S_t$ (MPa) | Surface area of mesh, $A_s$ ($m^2/m^3$) |
|---|---|---|---|---|---|
| Date palm fiber | 712 | 0.3–0.6 | 0.849–0.98 | 122 | 113.3–2013.3 |
| *Luffa aegyptiaca* | 433 | 0.3 | 0.926–0.946 | – | 442.9 |
| St. steel 316 | 7900 | 0.3 | 0.967–0.982 | 555 | 715.9–980.7 |

Table 2
Chemical Composition of the three wires

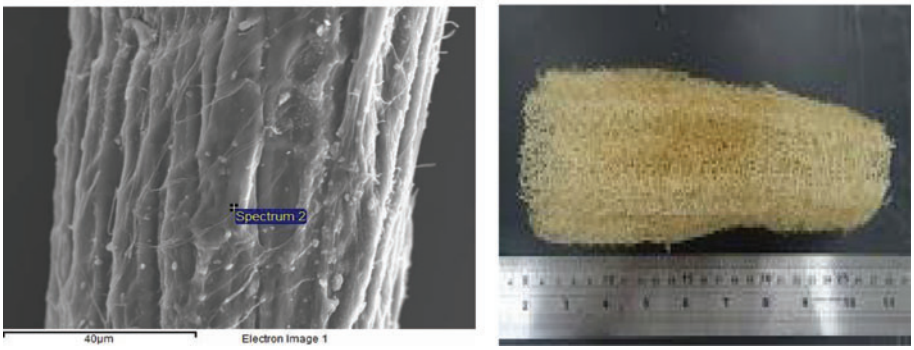
| Element | Stainless steel weight (%) | Data palm fiber weight (%) | *Luffa aegyptiaca* weight (%) |
|---|---|---|---|
| C | | 55.15 | 67.26 |
| O | | 22.64 | 28.75 |
| Cl | | 5.62 | 0.60 |
| K | | 15.07 | 0.73 |
| Ca | | 1.51 | 1.76 |
| Na | | | 0.23 |
| Mg | | | 0.17 |
| Al | | | 0.17 |
| Si | 0.20 | | 0.34 |
| Cr | 15.96 | | |
| Mn | 1.63 | | |
| Fe | 62.54 | | |
| Ni | 13.33 | | |
| Totals | 100.00 | 100.00 | 100.00 |



A- Date Palm Fiber



B Stainless Steel



C – Luffa Aegyptiaca

Fig. 2. The photos and the surface appearances of the three wires.

Any experimental procedure contains uncertainties, and error analysis is essential to attach significance to results. To estimate the uncertainties in the results presented in this work, the approach described by Barford [17] was applied. The overall uncertainty assigned to a given measurement is defined as the root-sum-square combination of the fixed error due to the instrumentation and the random error observed during measurements. Exercising this procedure, the calculations indicated errors of 2.4% for pressure drop, 2.31% for absolute pressure and 1.19% for air velocity. On the basis of these errors, the dry pressure drop departs by 4.6%.

## 3. Results and discussion

The effect of the air velocity (m/s) on the dry pressure drop, kPa/m of bed length, for the date palm fiber with 0.3 and 0.6-mm diameters and at constant porosity of 0.96 is shown in Fig. 3. The dry pressure drop through the wire mesh is due to air flow only. Normally, the dry pressure drop for the wire mesh demister is relatively small and increases with the air velocity. This effect is more pronounced at higher values of air velocities. Also, the figure illustrates that the dry pressure drop is inversely related to the wire size. This is caused by the increase of the wire surface area for smaller wire diameter (Eq. (1)). It is important to note that, the use of larger diameter wire is required to facilitate demister washing and cleaning. The use of larger diameter wire gives adequate mechanical strength and operational stability.

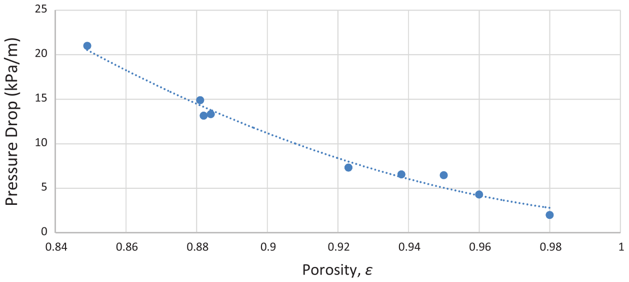


Fig. 4. The effect of pad porosity on the dry pressure for date palm fiber of 0.3-mm diameter at velocity of 4.7 m/s.

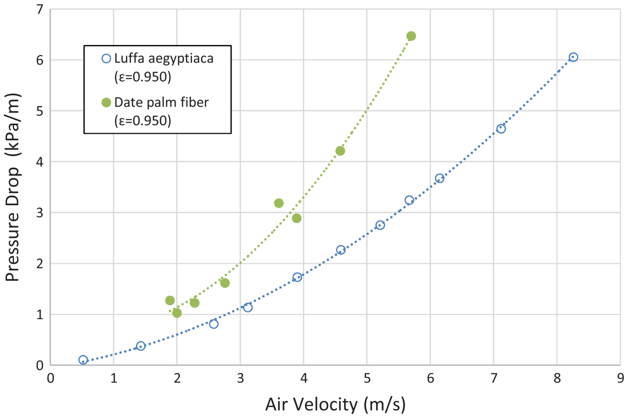


Fig. 5. The comparison between the dry pressure drop for the date palm fiber and the *Luffa aegyptiaca* both at 0.3-mm diameter at different velocities and constant porosity of 0.95.

Fig. 4 depicts the effect of pad porosity on the dry pressure for date palm fiber of 0.3-mm diameter. The dry pressure drop is inversely proportional to the bed porosity. Bed porosity is defined as the volume of the free space in the pad divided by the total volume of the demister (Eq. (3)). The increase of the pad porosity

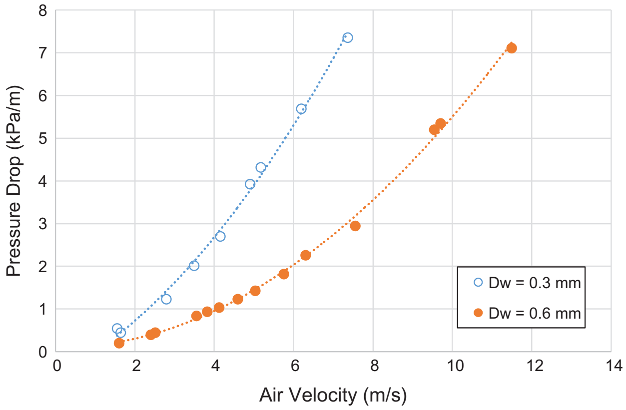


Fig. 3. The effect of air velocity on the dry pressure drop for date palm fiber with 0.3 and 0.6-mm diameters at porosity of 0.96.

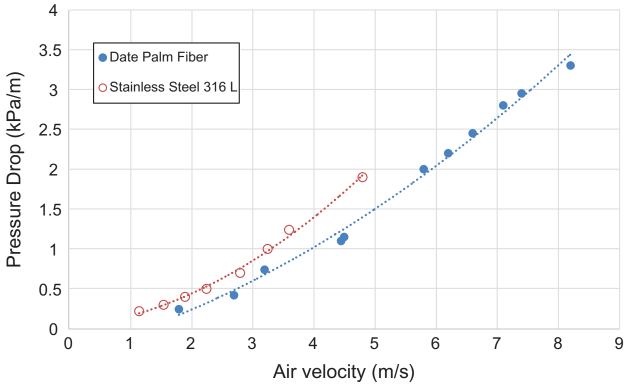


Fig. 6. The comparison between the date palm fiber and the stainless steel 316 L at 0.3-mm diameter and fixed porosity of 0.95.

Table 3
Operating and design ranges for the empirical equations

| Material | Velocity, $v$ (m/s) | Wire diameter, $d_w$ (mm) | Porosity, $\varepsilon$ |
|---|---|---|---|
| Date palm fiber | 0.26–12.65 | 0.3–0.6 | 0.849–0.980 |
| *Luffa aegyptiaca* | 0.47–10.01 | 0.3 | 0.926–0.946 |
| Stainless steel | 0.96–13.20 | 0.3 | 0.950–0.967 |

is associated with the decrease of air velocity inside the demister.

The comparison between the dry pressure drop for the date palm fiber and the *L. aegyptiaca* at different velocities and constant porosity of 0.95 is shown in Fig. 5. Also, the comparison between the date palm fiber and the stainless steel 16 L at fixed porosity of 0.95 is depicted in Fig. 6. It is clear that the effect of the air velocity on the dry pressure drop for the three wires has nearly the same trend. As it can be seen that, for the same operating conditions and wire diameter, the dry pressure for the date palm fiber is the minimum one followed by the *L. aegyptiaca*. The maximum pressure drop is observed when we used the stainless steel. This can be attributed to the surface appearances of the three wires shown in Fig. 2. These photos were documented by the scanning electronic microscope. The surface of the date palm fiber is relatively uniform with less number of irregularities compared to the *L. aegyptiaca*. The stainless steel wire has a lot of non-uniform spots with different heights. Also, there were some traces of deposits on its surface.

## 4. Correlation of the experimental data

In terms of the forgoing discussion, the dry pressure of the wire mesh mist eliminator is affected by air velocity ($V$), wire diameter ($d_w$), and bed porosity ($\varepsilon$). However, the diameters of the *L. aegyptiaca* and the stainless steel wire were constant. The least square fitting of the experimental data gives the following empirical correlations (Table 3):

(1) Date palm fiber

$$\Delta P = \exp(15.178 - 3.204\, d_w + 0.294\, v - 15.123\, \varepsilon)$$

(2) *L. aegyptiaca*

$$\Delta P = \exp(25.126 + 0.315\, v - 27.332\, \varepsilon)$$

(3) Stainless steel:

$$\Delta P = \exp(31.117 + 0.260\, v - 32.727\, \varepsilon)$$

## 5. Conclusions

In the current study, the performance of wire mesh mist eliminator made of date palm fiber is investigated experimentally. The obtained data are compared with the performance of industrial wire mesh demister made of stainless steel 16 L and *L. aegyptiaca* fiber. This study is limited to the measurement of the dry pressure drop using air as operating fluid. To the best of our knowledge, this is the first time to propose and evaluate the use of date palm fiber and *L. aegyptiaca* as materials of construction for the demisters in thermal desalination units.

Within the experimental ranges used, the following conclusions can be drawn:

1. The pressure drop in the wire mesh demisters is relatively small. However, its impact on the heat transfer driving force is significant especially in the low temperature desalination units.
2. The dry pressure drop in the demister pad increases with air velocity and is inversely related to the wire size and the pad porosity.
3. The effect of the air velocity on the dry pressure drop for the three wires has nearly the same trend.

At constant air velocity, wire diameter, and pad porosity, the dry pressure for the date palm fiber is the minimum one followed by the *L. aegyptiaca*. The maximum dry pressure drop is observed when we used the stainless steel wire.

## Acknowledgment

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## Nomenclature

$A_{\mathrm{s}}$ — specific surface area ($\mathrm{m}^{-1}$)
$d_{\mathrm{w}}$ — wire diameter (m)
$h$ — pad height (m)
$m_{\mathrm{mesh}}$ — mass of the mesh pad (kg)
$\rho_{\mathrm{p}}$ — pad density ($\mathrm{kg/m}^3$)
$\varepsilon$ — demister porosity, dimensionless

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