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CFD Modeling of Flotation Dryers

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Abstract. *This paper presents the results of a numerical and an experimental study of the effects of air bar and web interaction on the efficiency of the web design in flotation ovens. Two types of CFD modeling were developed and physical testing was conducted to verify these models. The physical testing showed that the air bar uniformity is generally less then* $\pm 2.5\%$ *cross machine direction and less then* $\pm 5\%$ *machine direction. The original modelling showed that the air leaving the air bars was completely uniform, and the new modeling showed some air non-uniformity. However, to get more accurate CFD modeling several more iterations will need to be done and the time required to get an accurate model will be greatly increased with each iteration.*

Keywords. numerical study · flotation ovens · CFD modeling · air flow uniformity · flotation dryers · air non-uniformity

Mathematics Subject Classification (2010): 76N15

1 Introduction

All of the literature which was reviewed from external sources, were studying the interaction of the air bars and the web. A web is a continuous strip of material that goes through the drying system. The published papers studied mostly the handling of the web, laterally, vibration, and stability of the web. For a web to go through these processes, it must be moved or handled in certain way [1]. Usually, this process is accomplished through automated equipment. The problem lies in the fact that while a web is being moved or handled by these automated machines, the web can become wrinkled, scratched, or in some way damaged. The process of concern in this paper is the drying of webs in flotation ovens or flotation dryers [1]. Often when a web is coated or printed on it must be dried before the surface of the web can be touched. This process may often be done in flotation ovens. In flotation drying the heated air can be directed from both the top and bottom of the web.

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The impinging air acts to accelerate drying and to float the web through the oven without making contact [1]. The object that directs this impinging air is called an air bar. Air bars come in many shapes, sizes, and designs [1]. In flotation ovens and dryers, the air is not only the means to dry the web but is also the means of supporting the web.

Perdue [1] experimentally studied the effects of air bar and web interaction for the purpose of proper web handling in flotation ovens. The importance of this investigation lies in the fact that understanding the physical processes involved in air bar and web interaction is crucial if web defects and coating damage are to be avoided. Effective methods to identify undesirable characteristics of flotation ovens can be developed possibly resulting in the development of a more desirable flotation device.

As direct pressure measurements on a moving and flexible web are not possible, non-contact techniques have been applied in many studies. Busch [2] used the optical methods to analyze the shape of the web. The image analysis allowed to obtain the necessary data from the computerized photographs or video images. The tension applied to the material was used to calculate the pressure and aerodynamic forces from the shape of the web across the air bar. The author concluded that the method cannot be used to interact with a controller and used as feedback to regulate the web position, but it can certainly give valuable information about the change in position.

Cho [3] developed an analytical air-web interaction model and its computational implementation. Theories of elasticity and fluid dynamics were applied to develop the aeroelastic model. As the continuous web running through multiple air bars is reduced to the web traveling over one air bar between two fixed supports, the web has been modeled as a traveling thread line assuming that the web is wide enough. This allows the web instability to be classified into a string-mode flutter [3]. The proposed model is effective for identifying the mechanism of air-web instability over pressure-pad air bars. The author also performed an experimental study to verify the developed analytical model. In these experiments the air dams were installed along both free edges of the web to block the air from escaping in the cross-machine direction, which kept air flows two-dimensional. Due to limitation of experimental set-up, these experiments were performed for the case of a non-traveling web exposed to air-jet flows. The experiments also were focused on effects of high-speed air flows on the flexible tensioned web. The velocity of the web was neglected because the velocity of the air jet is much higher than the translational velocity in practical applications. Stability criteria were provided and compared through experiments and computations in this study.

Smith [4] performed physical testing of air bars and provided the details of the test procedures. In order to reduce the cost of dryers, a new design was created that is projected to reduce the price by about 40 – 60 %. This new design allowed to control the air handling within the system. Since the air handling changed, the author concluded that it is necessary to develop the CFD models and to conduct a physical testing in order to confirm that the new design meets the product requirements.

Objective

The objective of this study is developing CFD modeling of flotation dryers in order to optimize their production and cost. An accuracy of the CFD modeling was determined using the experimental data obtained in the production line.

Experimental study

The experimentation for this study was done in three different ways: on-site testing, previous CFD modeling, and a new CFD modeling. A new drying module was designed and manufactured in Poland. To help certify the new design shown in Fig. 1, on-site testing was performed. Currently, phase two of this project is underway. This phase will also include onsite testing. However, this testing will be more in-depth than the previous testing. Part of phase one testing was air bar uniformity testing, where the air leaving the nozzles were measured. A model of the air bar is presented in Fig. 2. The testing procedure for this test is as follows.

The air bars were set to the distance of 3/8 inch distance from top to bottom. The frequency drive was set at five different frequencies. It was noted that the upper and lower supply dampers could not be 100% open. The maximum it can be open is about 85-90%. The supply dampers are shown in Fig. 3 and 4. The upper and lower dampers were not balanced and the upper and lower header pressures were measured through the pressure ports (Fig. 5). In this figure, the blue, green and red arrows are for the fan pressure, for the upper and the lower headers, respectively. A modified pitot tube was used to measure the pressure at four points across each air bar. The pitot tube was modified by flattening down the end and then sanding it down to fit in the slots of the air bars. These locations can be seen by the blue arrows in Figure 6. This modification allowed to acquire the slot pressures easier and more consistent. A summary of the data collected can be seen in Table 1.

Fig. 1. New Oven Design

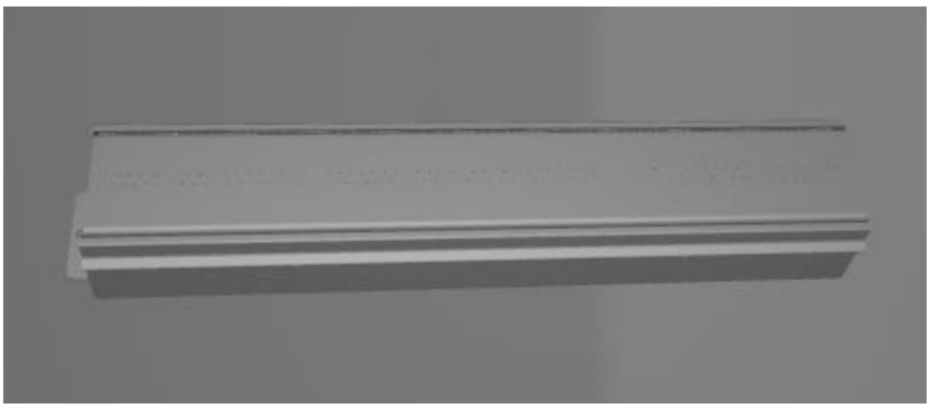

Fig. 2. Standard Flotation Air Bar

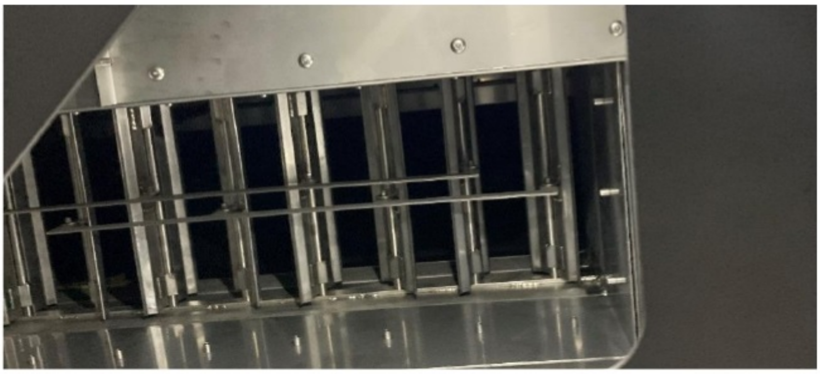

Fig. 3. Lower Header Damper

Fig. 4. Upper header damper

Fig. 5. Pressure ports for fan, upper and lower headers.

Fig. 6. Slots where the air bar pressure was measured

Table 1. Summary of air bar uniformity testing.

Test 1					
Bottom			Top		
	ft/min	m/s		ft/min	m/s
Avg. Velocity	6759	34.33	Avg. Velocity	6411	32.56
Max. Velocity	6930	35.19	Max. Velocity	6587	33.46
Min. Velocity	6622	33.63	Min. Velocity	6274	31.86
	high (%)	low (%)		high (%)	low (%)
Machine Direction	2.52	2.02	Machine Direction	2.752	2.134
Cross machine (highest value)	0.98	1.00	Cross machine (highest value)	0.960	1.024
Test 2					
Bottom			Top		
	ft/min	m/s		ft/min	m/s
Avg. Velocity	5903	29.98	Avg. Velocity	5578	28.33
Max. Velocity	6005	30.50	Max. Velocity	5728	29.09
Min. Velocity	5780	29.36	Min. Velocity	5432	27.59
	high (%)	low (%)		high (%)	low (%)
Machine Direction	1.73	2.07	Machine Direction	2.704	2.610
Cross machine (highest value)	1.73	1.15	Cross machine (highest value)	1.285	1.466
Test 3					
Bottom			Top		
	ft/min	m/s		ft/min	m/s
Avg. Velocity	4494	22.82	Avg. Velocity	4272	21.70
Max. Velocity	4644	23.59	Max. Velocity	4433	22.51
Min. Velocity	4298	21.83	Min. Velocity	4026	20.45

	high (%)	low (%)		high (%)	low (%)
Machine Direction	3.35	4.36	Machine Direction	3.767	5.754
Cross machine (highest value)	2.53	1.73	Cross machine (highest value)	3.971	2.286
Test 4					
Bottom			Top		
	ft/min	m/s		ft/min	m/s
Avg. Velocity	3178	16.14	Avg. Velocity	3026	15.37
Max. Velocity	3267	16.59	Max. Velocity	3112	15.81
Min. Velocity	3101	15.75	Min. Velocity	2949	14.98
	high (%)	low (%)		high (%)	low (%)
Machine Direction	2.82	2.39	Machine Direction	2.830	2.558
Cross machine (highest value)	2.91	1.92	Cross machine (highest value)	1.857	1.280
Test 5					
Bottom			Top		
	ft/min	m/s		ft/min	m/s
Avg. Velocity	2481	12.60	Avg. Velocity	2424	12.31
Max. Velocity	2553	12.97	Max. Velocity	2553	12.97
Min. Velocity	2422	12.30	Min. Velocity	2340	11.88
	high (%)	low (%)		high (%)	low (%)
Machine Direction	2.92	2.37	Machine Direction	5.300	3.491
Cross machine (highest value)	1.22	2.47	Cross machine (highest value)	1.505	2.207

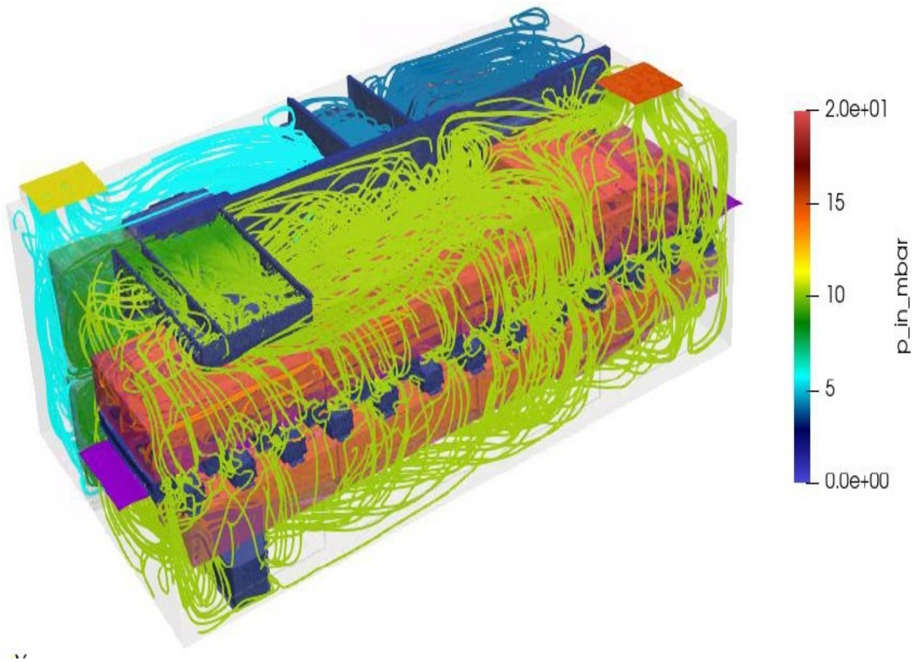

Fig. 7. Previous CFD model #1

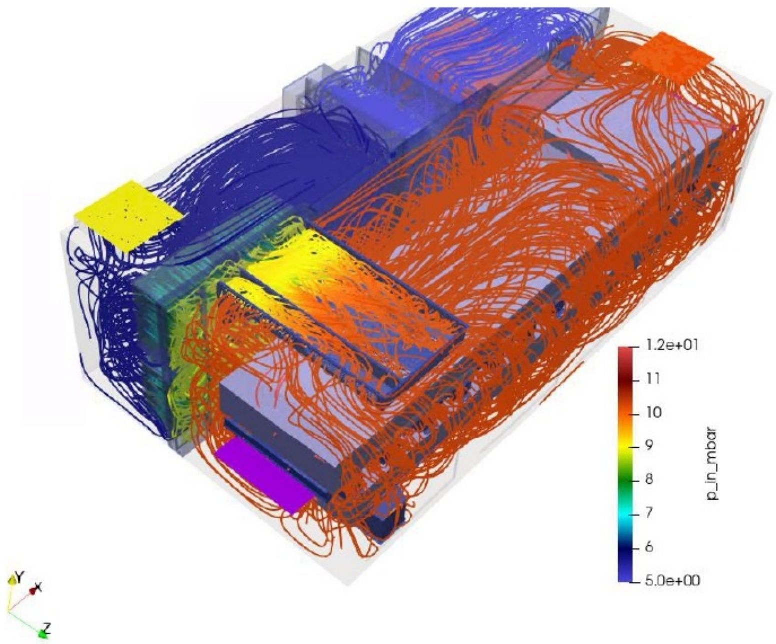

Fig. 8. Previous CFD model #2

CFD models

The previous CFD models #1 and #2, which were run internally at The Dürr Group Co., are presented in Fig. 7 and 8, respectively. Both models showed a very uniform exit nozzle pressure. The models can be used to predict a very uniform nozzle velocity. This can resolve many problems happened in real production line. The nozzle almost directly under the supply duct on the long side of the header tends to have uniformity issues. But this was not seen in the previously ran models.

A new CFD modeling was performed on just the air bar. A performance of the newly developed model is shown in Fig. 9. As seen from this figure, the air flow favored one slot over the other. This non-uniformity could have been caused (i) by the modeling set up or (ii) by the air flow going through the air bars favor one slot over the other. Hence, more testing will be required in the near future.

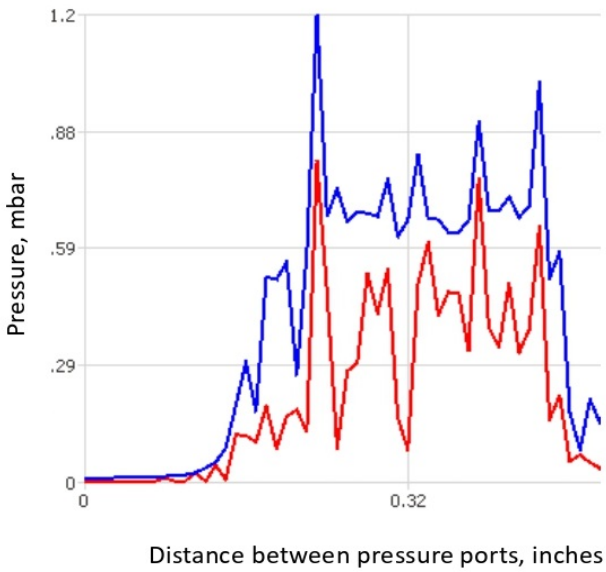

Fig. 9. CFD Air pressure model of air bar

2 Conclusions

In conclusion, the CFD modeling overall shows on average accurate data. However, if we look at each individual air bar and points on the air bars, discrepancies show up. It is assumed that the discrepancies started at the fan and the turns in the ductwork. The next part in question will be the interaction of the air going from the ducts to the header and the perforated plates in the air bars. The needed time and iterations needed to get an accurate model would be extremely high, and would be unreasonable to do at this time. Regardless, the developed new CFD model is accurate enough to be used to approve the overall design. More on-site testing will be done in the near future, which will include measuring the air flows in the supply ducts, headers and air bars. This additional data will also be compared to the CFD modeling to either confirm the modeling or request changes to the modeling to increase its accuracy.

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