# NEW FINDINGS OF ENTRAINED AIR AND DISSOLVED GASES IN PM WET END: MILL CASE STUDY


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## ABSTRACT

Entrained air and dissolved gases were studied in a mill with three paper machines producing different paper grades. Along with entrained air, dissolved gas is also an important component. The balance between these two states changes rapidly in different locations of the process, depending on the type of equipment and chemicals used. For example, the headbox can have a big influence on the final volume of entrained air on the former. The defoamer chemical changes the balance from entrained air into dissolved gases. By understanding the behavior of air and gases in the process, it is possible to bring the operation of the papermaking process and the final paper quality to an optimum level.


Good quality stock is the basis for efficient and competitive paper manufacturing. Papermakers know that the stock contains -- in addition to fibers, water, and a selection of process chemicals -- also some air and gases. However, it is not so well known how much air there actually is in the stock, how the volume of air varies by time, and how and where the air has a negative influence on the papermaking process. The presence of entrained air in stock should not be forgotten when performing the process measurements and studies, and making conclusions of them.

UPM-Kymmene Corporation, Jämsänkoski mill and Ahlstrom Machinery Corporation in Finland analyzed in two years' time the process circumstances related to entrained air bubbles and dissolved gases in the stock. Three paper machines producing different paper grades were studied in the tests. Specifications for the three machines are listed in **Table I**.

***Table I.*** *UPM-Kymmene, Jämsänkoski: paper machine specifications*

| Machine | PM3 | PM4 | PM6 |
|---|---|---|---|
| Paper grade | WFU, WFC (Wood-free uncoated for label paper and wood-free coated for label paper) | MFC (Matte coated offset paper) | SC (Supercalandered magazine paper) |
| Production (tn/a) | 65,000 | 100,000 | 320,000 |
| pH | Neutral | Neutral | Acidic |
| Max. speed (m/min) | 600 | 780 | 1600 |
| Former | Fourdrinier | Fourdrinier with Sym Former R | Speed Former HS2 |
| Deaeration | No | Yes | Yes |
| Year built | 1960–1989 | 1974–1987 | 1992 |

The objectives of the study were to analyze the behavior of entrained air and dissolved gas in a modern papermaking process, and -- depending on the findings -- improve or optimize the manufacturing process.

## 1. Air and Gases in Papermaking Stock

**Figure 1** illustrates the behavior of air in stock and the balance between entrained air and dissolved gas.

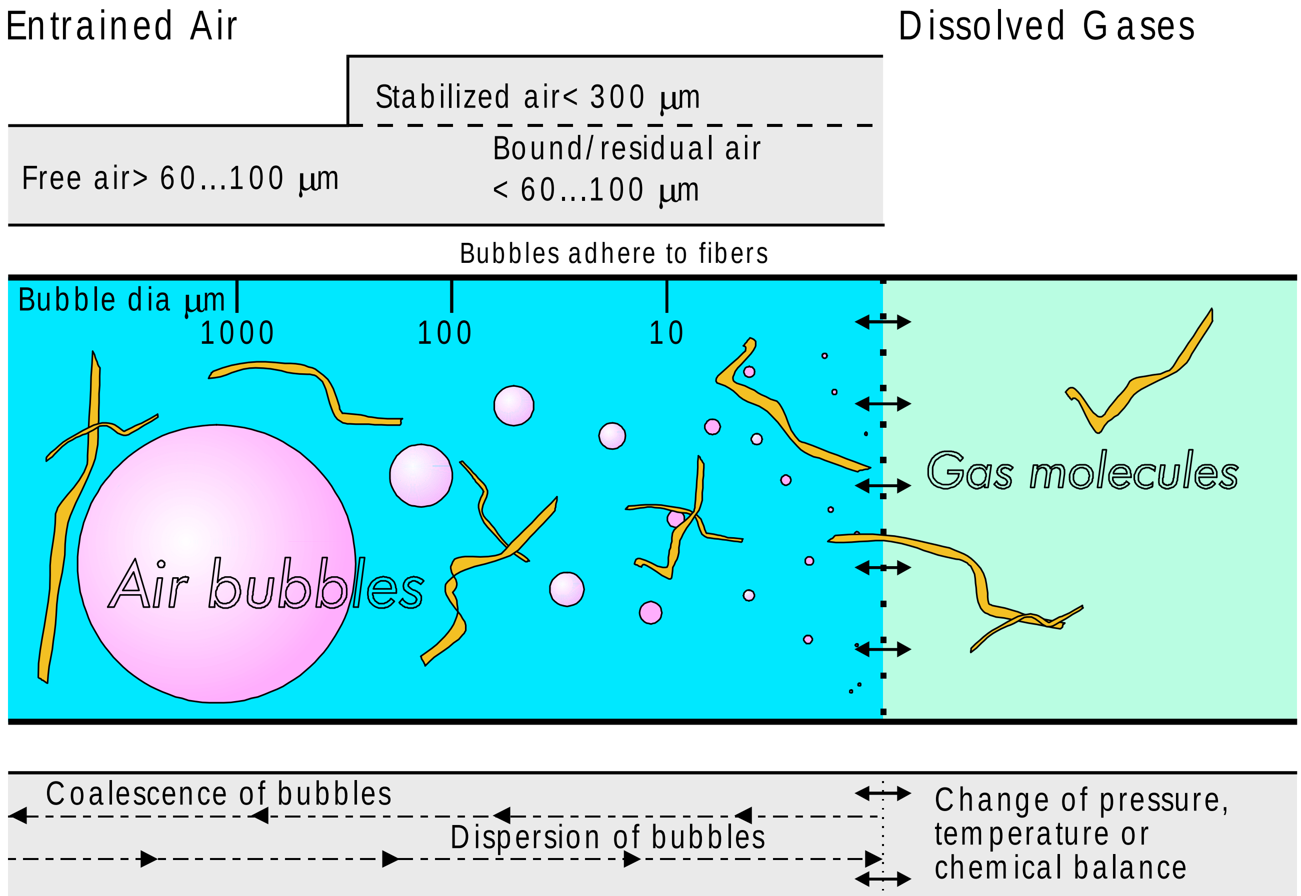



*Fig. 1.* *Air in stock: entrained air – dissolved gas*

**Entrained air** (air bubbles)**:**

- Free air: This is freely moving air bubbles in the stock. The size of an individual air bubble is clearly larger than 70–100 µm in diameter.
- Bound or residual air: The size of a bound air bubble is small enough to adhere to fibers, i.e., smaller than 70–100 µm in diameter. It can also be found inside a fiber, especially if the pulp has been dried (broke or baled pulp) before processing. Small air bubbles can also build fiber flocs through adhesion.

**Dissolved gases** (gas molecules)**:**
Dissolved gases are different individual gases that have been dissolved into water through the walls of air and gas bubbles. Chemical or biological activities can also produce dissolved gas directly into the water. Dissolved gas is always present as molecules in the water. The quantity of dissolved gas in the stock often exceeds the quantity of entrained air.

The relative portion of entrained air and dissolved gases is affected by the stock temperature, pH, the pressure, the chemicals used, and the total air/gas content.

### 1.1 Entrained air

**Size**: Air bubbles in the papermaking stock are small. The average size of a stabilized air bubble is approximately 100 µm, which is also the average critical size still visible for a human eye *(1, 2)*. **Table II** shows a summary from the studies analyzing the air bubbles in the PM wet-end area.

***Table II.*** *The sizes of stabilized entrained air and gas bubbles in the papermaking stock (sizes may vary mill by mill)*

| | |
|---|---|
| Minimum size | 10 µm |
| Maximum size | 300 µm |
| Most common size range | 30–170 µm |
| Average size | **100 µm** |

Even though the entrained air bubbles are very small, the total volume of entrained air in the stock is often considerable. That is why the total number of the tiny bubbles can be surprisingly high. Let us study a volume of approximately one liter of stock, and let us assume that the average bubble size is 100 µm, as shown in Table II. The number of air bubbles with different air quantities is presented in **Table III**.

***Table III.*** *The number of entrained air bubbles with different air volumes in one liter of stock*

| Air % (volume) | 0.01% | 0.05% | 0.1% | 0.5% | 1.0% | 2.0% |
|---|---|---|---|---|---|---|
| Number of bubbles | 200,000 | 1 million | 2 million | 10 million | 20 million | 40 million |

**Volume:** The volume taken by bubbles in the stock is often greater than the volume taken by fibers.
*Example:* Case: Stock fiber consistency of 0.7% with 2.0 vol.% entrained air.
Air takes approximately twice the volume of the fibers. If the air content is 1.0%, the volumes of fibers and entrained air are roughly the same.

**Quantity:** The number of 100-µm-diam. bubbles is also greater than the number of fibers in the stock.
*Example:* Case: Stock fiber consistency of 0.7% with only 0.2 vol.% entrained air.
There are 2.5 million fibers with the length of approximately 1 mm in one liter of stock, whereas the number of entrained air bubbles is as high as 4 million.

**1.2 Dissolved gases**

Besides the entrained air bubbles, individual gases of the air can also dissolve into the stock water as individual molecules. If the liquid pressure increases, the dissolving capacity will also increase, and the number and volume of entrained air bubbles will decrease. An increase in the stock temperature will reduce the gas dissolving capacity, and the dissolved gas molecules will be released into bubbles. For example, 40°C stock can hold more dissolved $CO_2$ than 50°C stock. A decrease in the water surface tension increases the rate of the dissolving process in both directions. Defoamers have a significant influence on surface tension.

The balance between dissolved gases and entrained air in the stock changes continuously and often rapidly in the process. It is important to know both these “components” of air in order to understand what is going on and how the process behaves in various situations.

In a down-to-earth comparison, **Fig. 2**, the air and gas content in the stock is compared with some favorite drinks to make it easier for the reader to realize the importance and magnitude of dissolved gases in the papermaking stock. Some paper machines may have more dissolved gases in the stock than there is dissolved $CO_2$ in sparkling wine.

Comparison of Stock to Quality Wine, Soda, Beer and Sparkling Wine

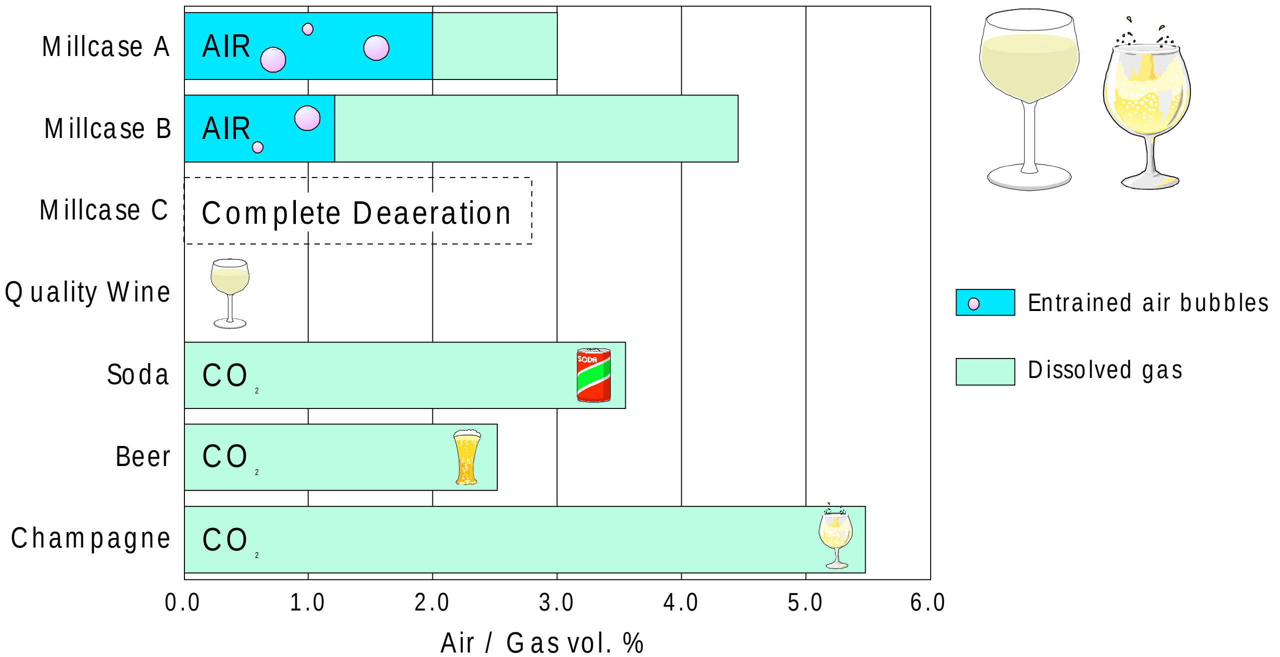



***Fig. 2.*** *Comparison of stock to wine, soda, beer, and sparkling wine*

**2. Sources of Air in the Papermaking Process**

The headbox approach system on the paper machine is basically a closed and pressurized process to treat and transfer stock to the headbox. The routes of air having access into the system can easily be located:

**Thick-stock feed:** A thick-stock line is led to the lower part of the white water silo or wire pit. In the stock preparation process, some air and gases are mixed into the thick stock. A typical "air mixer" is a chest agitator running blades close to or partly above the surface in the chest. The pipes discharging water or stock above the surface, some overflow arrangements, and leaking seals operating under vacuum are all efficient ways to bring air into the process. Coated broke contains carbonate as coating pigment, which will easily dissipate to $CO_2$ gas. Biological activity can also bring gases into the system.

The air content in the thick-stock line is typically as follows: entrained air 1–2%, dissolved gases 1–2%, and the total air content 2.5–4%. The volumetric flow of the thick-stock line is relatively small compared with the total flows in the PM approach system. That is why only 15–20% of the total air volume entering the approach system comes through the thick-stock line.

**White water circulation**: The dewatering elements of the former/wire section remove water from the web. On a modern machine, dewatering is a fast process. The removed water sprays, falls, splashes, and runs on the guiding plates and finally into the white water trays. The process mixes air very efficiently into the white water on its way back to the white water silo.

The air content varies greatly by machine, mainly depending on the style and construction of the wire section and the type and content of the solids in the white water. The total air content of the tray water is normally 2–4% by volume.

**3. Presence and Behavior of Entrained Air and Dissolved Gases in the Process; Deaeration of the Papermaking Stock and White Water**

In the PM approach system, there are two locations where entrained air and gases can be removed: the surface of the white water silo or wire pit and the stock deaerator, **Fig. 3**.

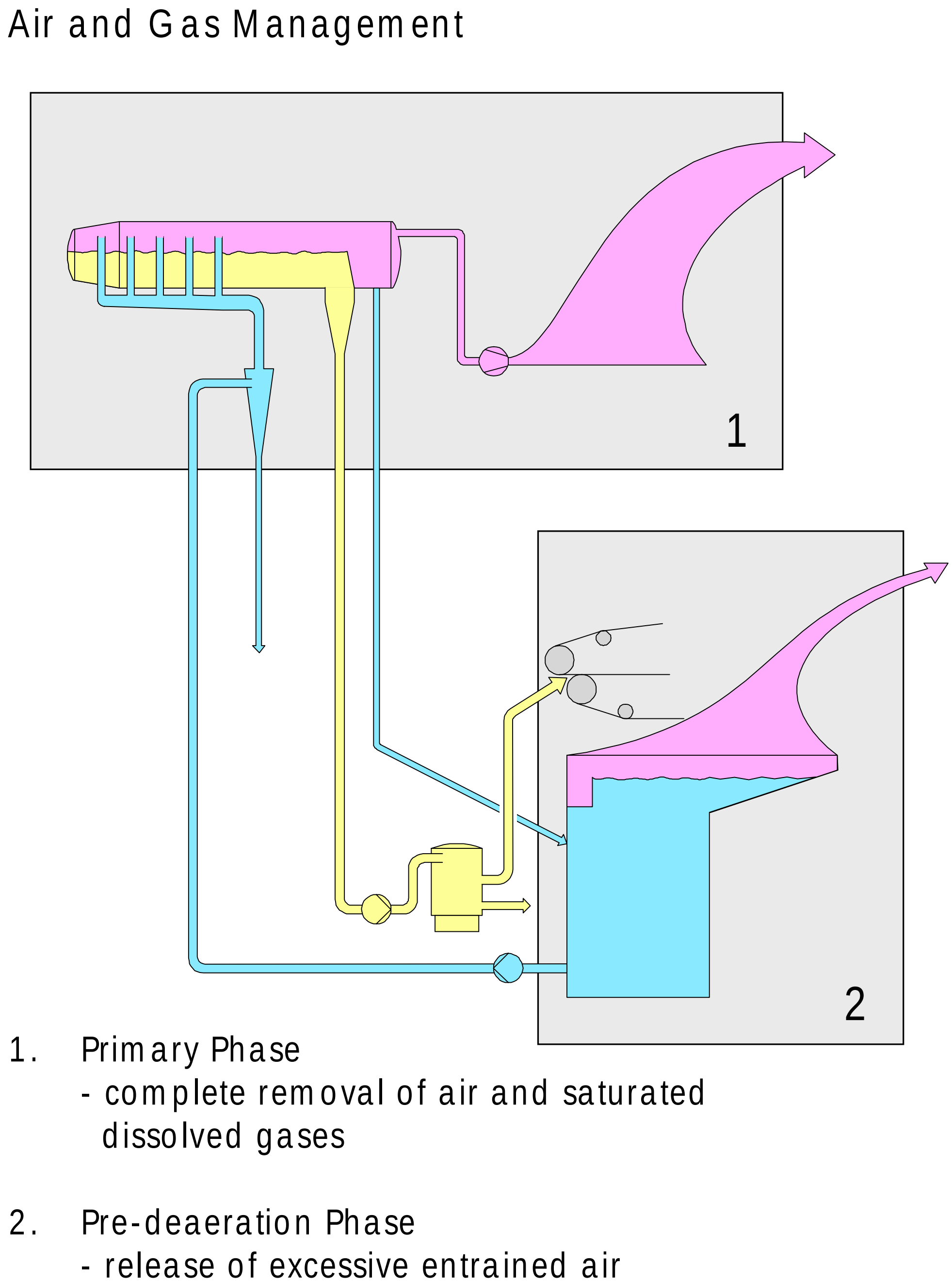



*Fig. 3.* *Air and gas management*

**3.1 Operation of the white water silo or wire pit as a passive deaerator**

The main tasks of a white water silo or a wire pit are to: mix efficiently various flows entering the silo, deliver a homogenous pulse-free stock flow to the primary cleaner feed pump, operate as a white water storage, and remove excess air from the white water entering the topmost part of the silo.

The conventional sizing criterion for air removal in a white water silo is quite simple: The falling velocity of white water in the silo must be between 0.1 and 0.15 m/s. The principle is that the upward velocity of entrained air bubbles is higher than the falling velocity of white water. When the equation is true, the bubbles rise to the surface of the white water because of their buoyant force.

If the falling velocity is too high, the flow will take the bubbles down and no air will escape. If the white water velocity is too slow, it can cause slime or dirt buildup in the silo.

With small air bubbles, the buoyant force is accordingly small, too. That is why there has to be time and room for the bubbles to grow larger through coalescence. The bubbles to be removed with the above principle should be at least 1 mm in diameter. It requires one thousand of 0.1-mm bubbles to generate a single air bubble of 1.0 mm.

In the measurements, we learned that white water silos are not always efficient for deaeration. In practice, only a small part of the total volume of entrained air in the white water can be released in the white water silo. The air distribution in the inlet and outlet flows of a white water silo is presented in a simulation example in **Fig. 4**.

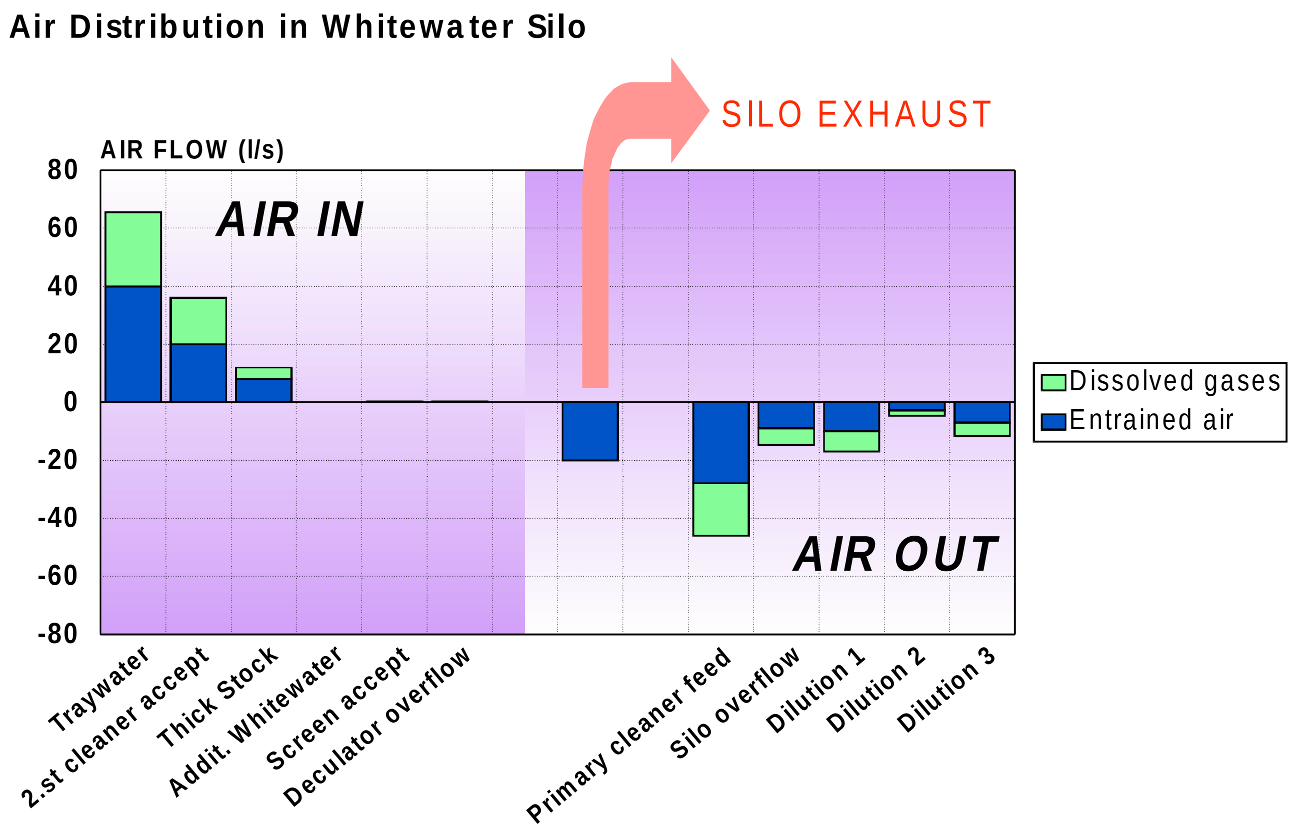



***Fig. 4.*** *Air distribution in white water silo*

The use of a defoamer chemical can improve deaeration efficiency up to a certain point. Excessive dosage of chemicals will not bring additional efficiency. Defoamers decrease the surface tension of a liquid, which helps the bubbles to coalesce and grow bigger and therefore rise up faster. The chemicals must be added to the process before the white water enters the silo. The best and most effective locations were found by testing and measuring the results.

**3.2 Pumps**

More than half of the entrained air in the PM approach system can be dissolved in the primary cleaner feed pump. The pressure increase in the pump is 200–300 kPa. The total air/gas content will be the same because there are no escape routes for air in the pump. Gases of the entrained air will dissolve, increasing the quantity of dissolved gases, whereas the amount of entrained air will decrease, as seen in **Fig. 5**.

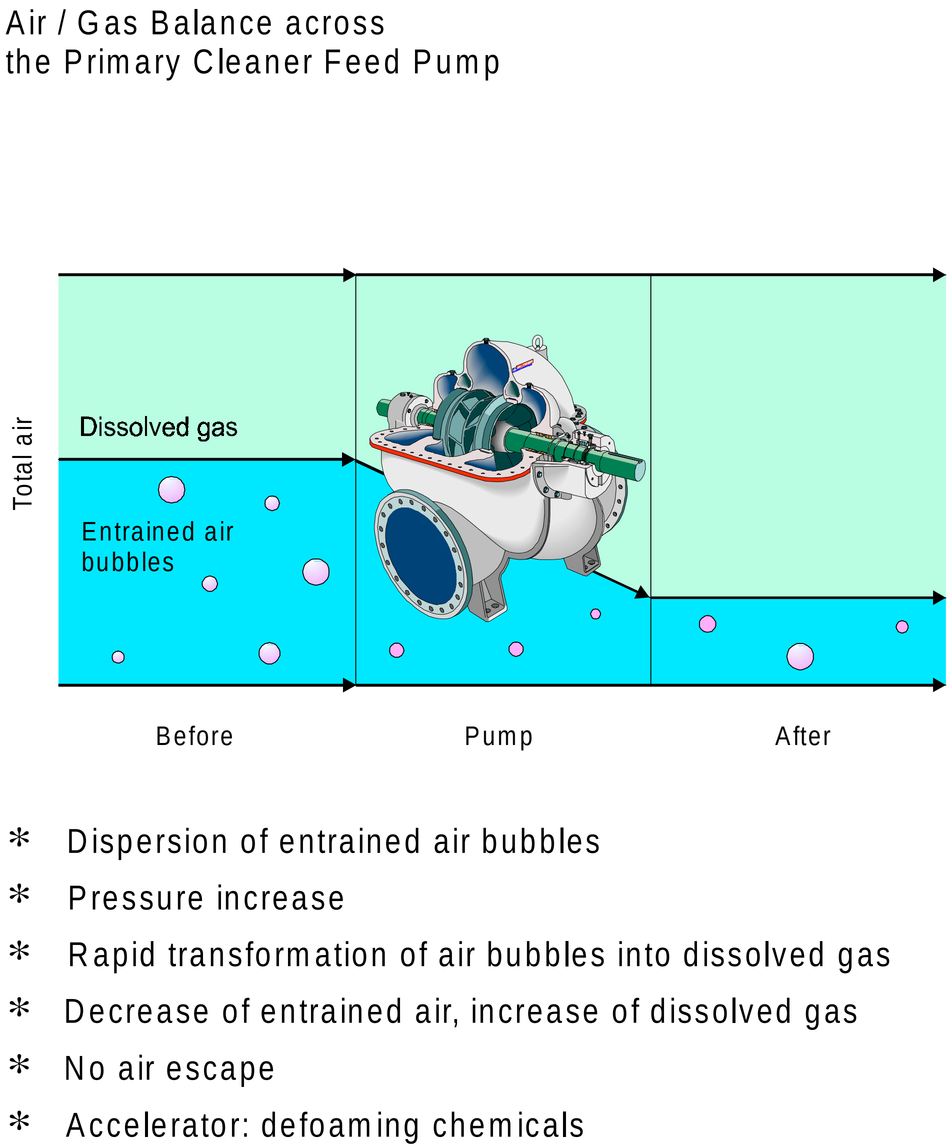



***Fig. 5.*** *Air–gas balance across the primary cleaner feed pump*

The dissolving process of the bubbles is apparently due to the pressure increase, strong shear forces, and rapid dispersal of the bubbles. The change of the balance between entrained air and dissolved gases was recorded with each paper machine studied during the tests. The use of a defoamer chemical increases the sensitivity of the change. **Figure 6** shows how the balance between entrained air and dissolved gases changes across a cleaner feed pump. The particular test was carried out with two different defoamer dosage levels prior to the white water silo.

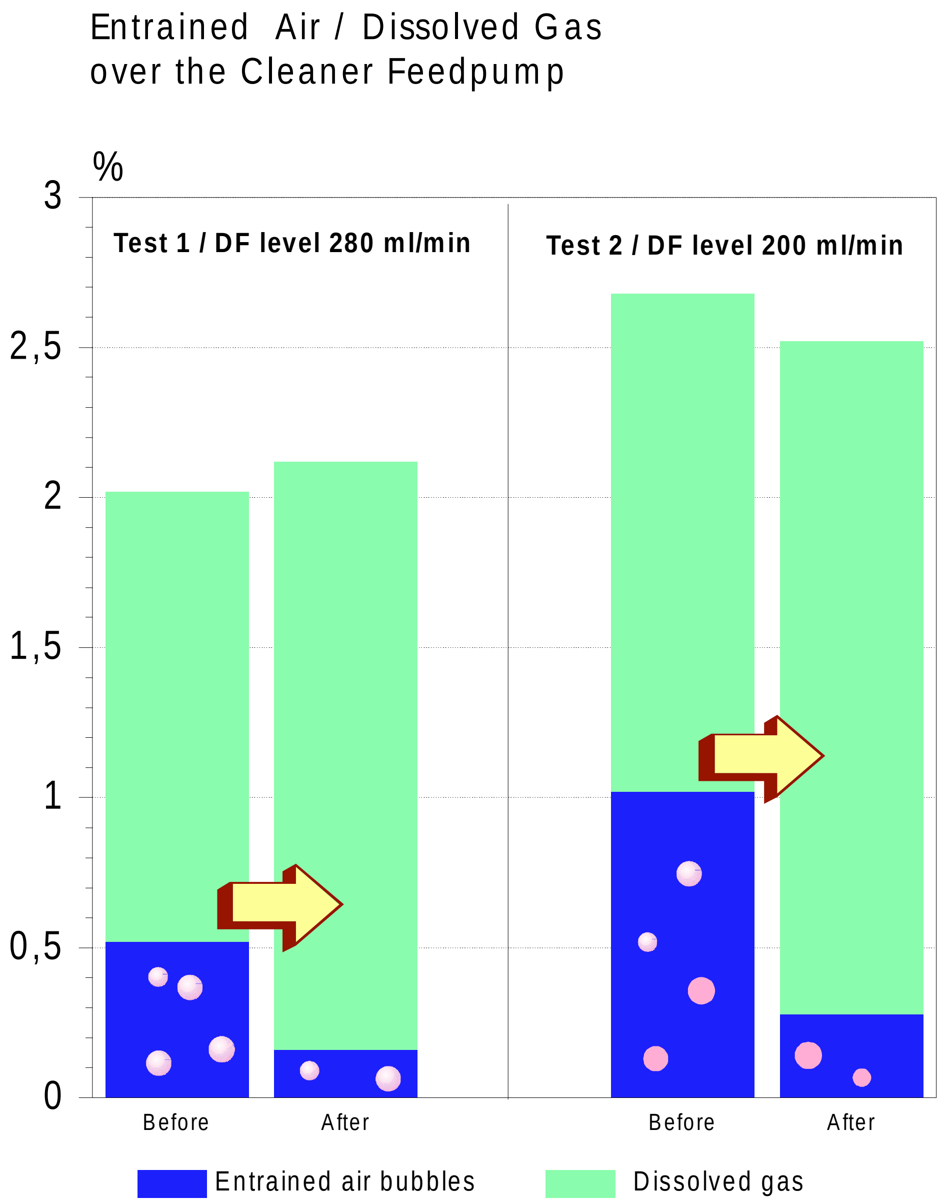



***Fig. 6.*** *Air–gas balance across a cleaner feed pump at two levels of defoamer addition*

**3.3 Deaeration in a physico-mechanical deaerator**

An efficient method to remove air is a physico-mechanical deaeration vessel. The basic elements for an efficient and complete deaeration are spraying, hydraulic impingement, and boiling of the stock under vacuum corresponding to the stock temperature.

The deaeration process, illustrated in **Fig. 7**, removes entrained air and dissolved gases completely. The stock entering the headbox after the deaerator is practically free from entrained air bubbles, and it is strongly undersaturated with dissolved gases. In a way, the stock is "hungry," with a strong capacity to dissolve more gases into water. This will hold the gases dissolved all the way from the deaerator to the former through the headbox, and it will also prevent the formation of new air bubbles. It is crucial that the vacuum system of the deaeration process runs well, its capacity is big enough, and the operation and mechanical conditions are regularly serviced and maintained. The deaeration results with the different paper machines tested are presented in the entrained air and dissolved gas balance figures.

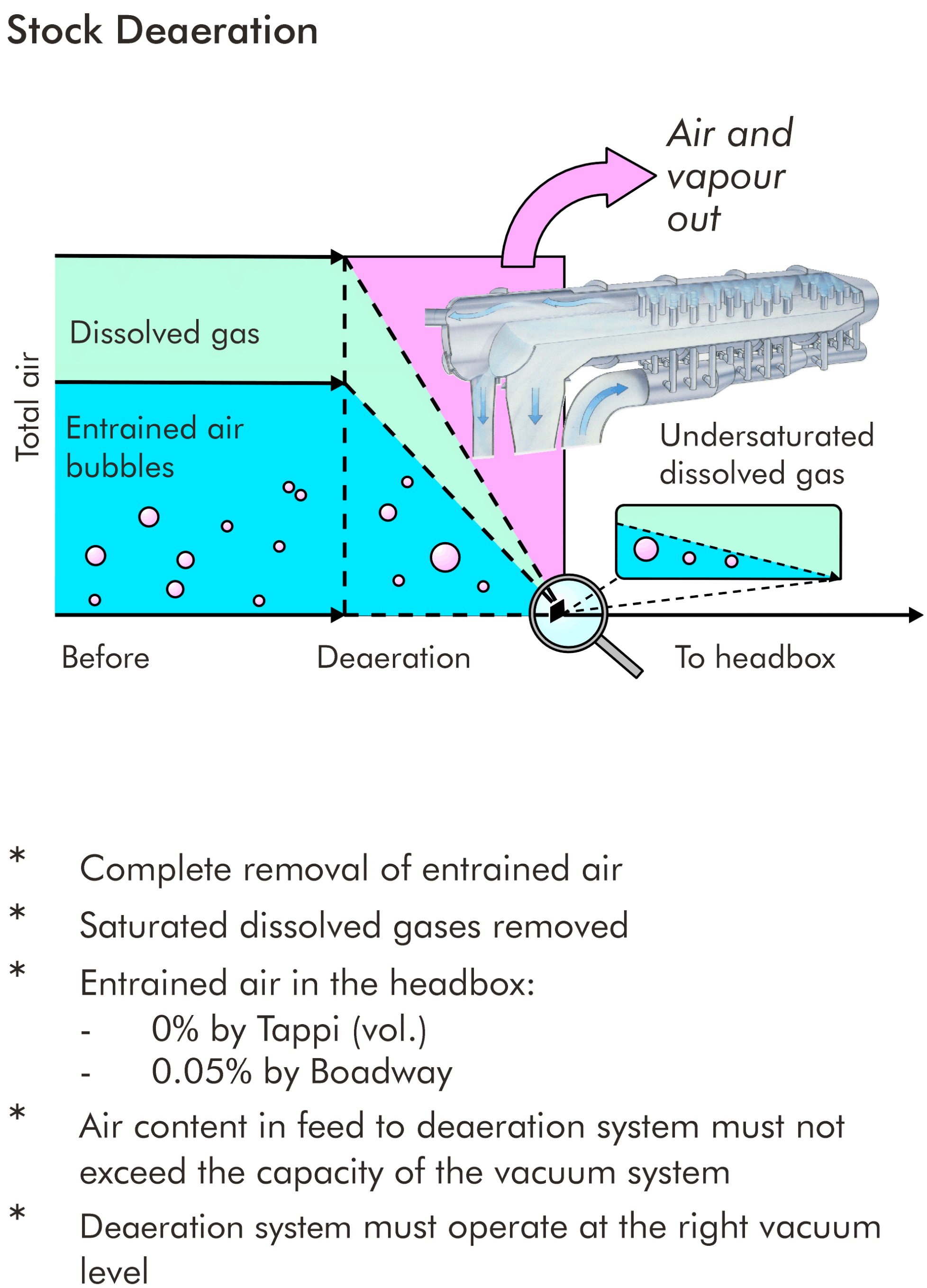



***Fig. 7.*** *Stock deaeration*

**3.4 Headbox and wire section of a paper machine**

If a machine operates without an efficient deaeration, there are supersaturated dissolved gases in the stock. The entrained-air content before the headbox can be quite low, e.g., 0.2–0.5%, especially if defoamer chemical is used. However, the amount of dissolved gases can be 2–3% or even higher.

The dissolved gases do no harm on the wire if they stay dissolved. However, the saturated and supersaturated dissolved gases can easily change back into tiny entrained air bubbles. The rate of change is highest with modern, pressurized hydraulic headboxes. Microturbulence, significant velocity differences, and a large pressure drop from the feed manifold to the slice flow will let the dissolved gas molecules form new air bubbles. The higher the slice velocity and the pressure difference in the headbox, the greater is the change.

The change in the state of gases in the stock across the headbox was demonstrated in the tests with a modern hydraulic test pilot headbox, illustrated in **Fig. 8**. Apart from the slice width, which was approximately 75 mm, the dimensions of the headbox were the same as with a normal production unit. The test was performed on three different paper machines. The test unit was installed on a side line, and stock was fed to the pilot headbox after the primary cleaner feed pump, before deaeration. So accordingly, prior to the pilot headbox, the stock in all three cases was saturated or supersaturated with dissolved gases and contained some entrained air too.

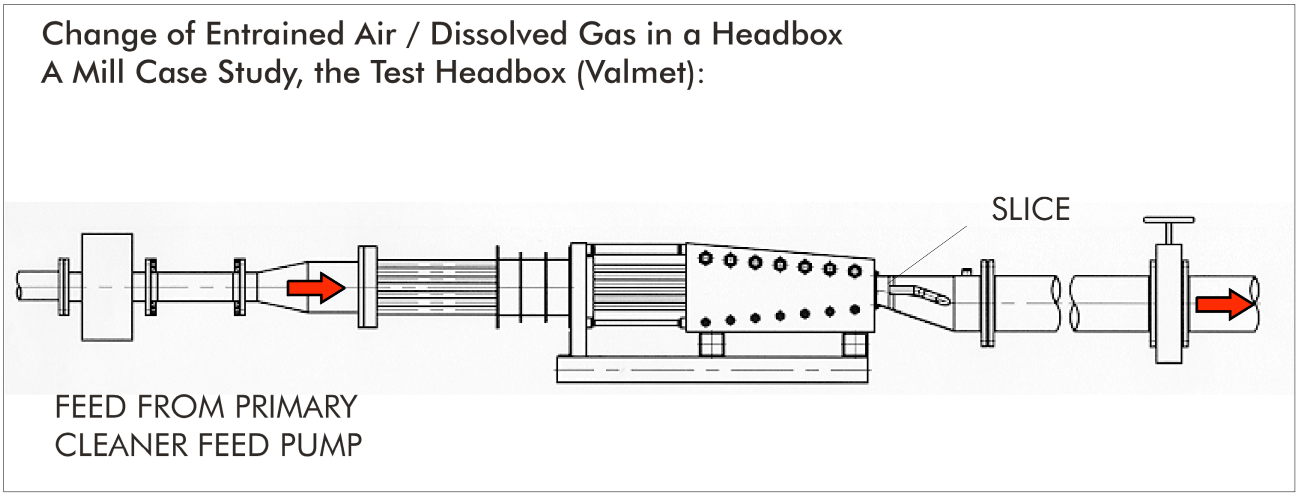



***Fig. 8.*** *Pilot headbox*

**Figure 9** presents the measured contents of entrained air and dissolved gas in the feed manifold and in the slice flow. The entrained-air content is clearly higher in the slice flow than in the feed manifold. The total air content stays about the same. **Figure 10** shows the same result with only the entrained-air content presented. The changes in the entrained-air content were as follows: MFC machine, 3.1 times higher; SC machine, 3.3 times higher; and WFU/C machine, 5 times higher entrained-air content in the slice flow than in the feed manifold. These numbers were recorded with the maximum flow and slice velocity. With a lower velocity, the change of the state of air was respectively smaller.

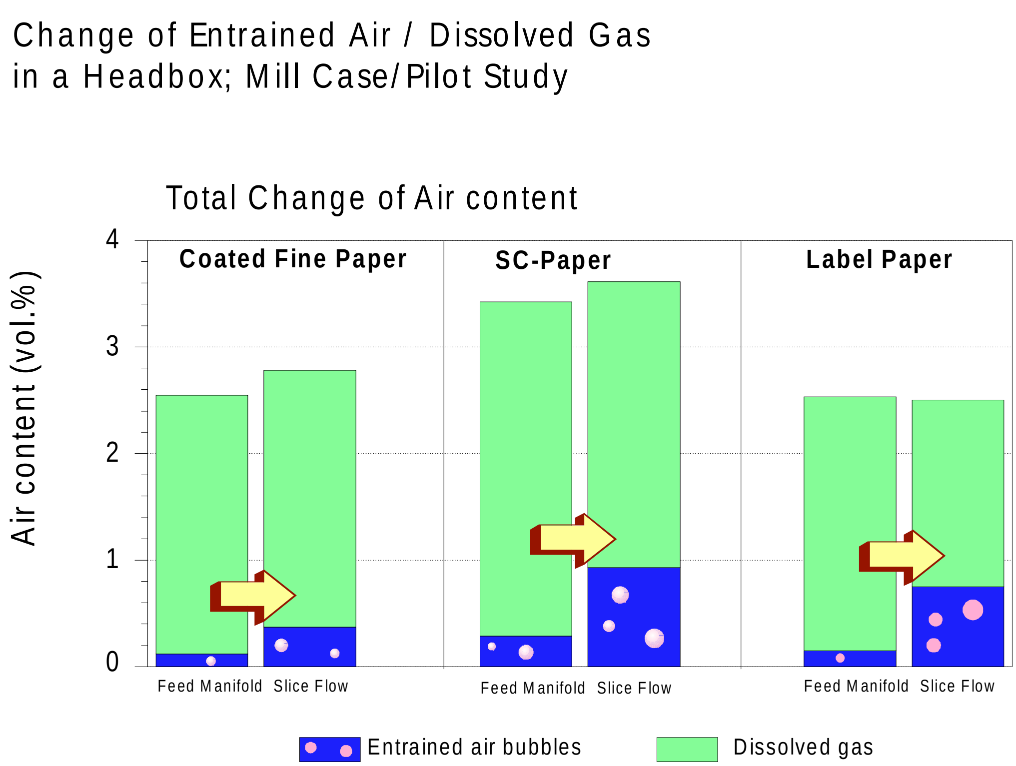



***Fig. 9***. *Air–gas balance in the feed manifold and the slice flow on three paper machines*

## Change of Entrained Air / Dissolved Gas in a Headbox; Mill Case/Pilot Study

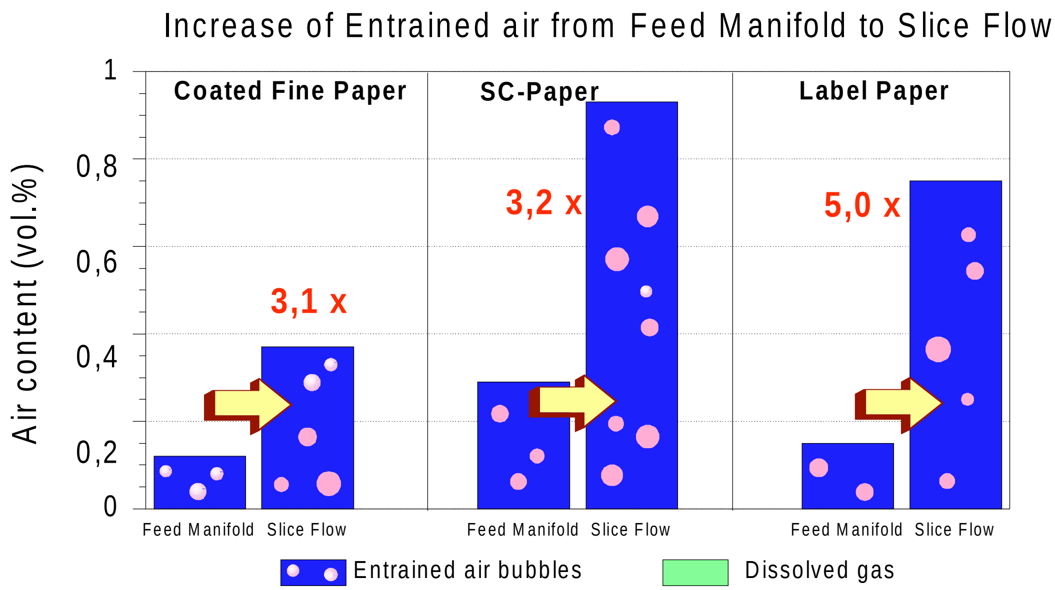



*Fig. 10. Increase of entrained air from feed manifold to slice flow*

**Figures 11, 12, and 13** show the entrained-air contents of the slice flow following the changes of the slice velocity for the machines producing supercalendered, wood-free label paper, and matte coated offset paper, respectively.

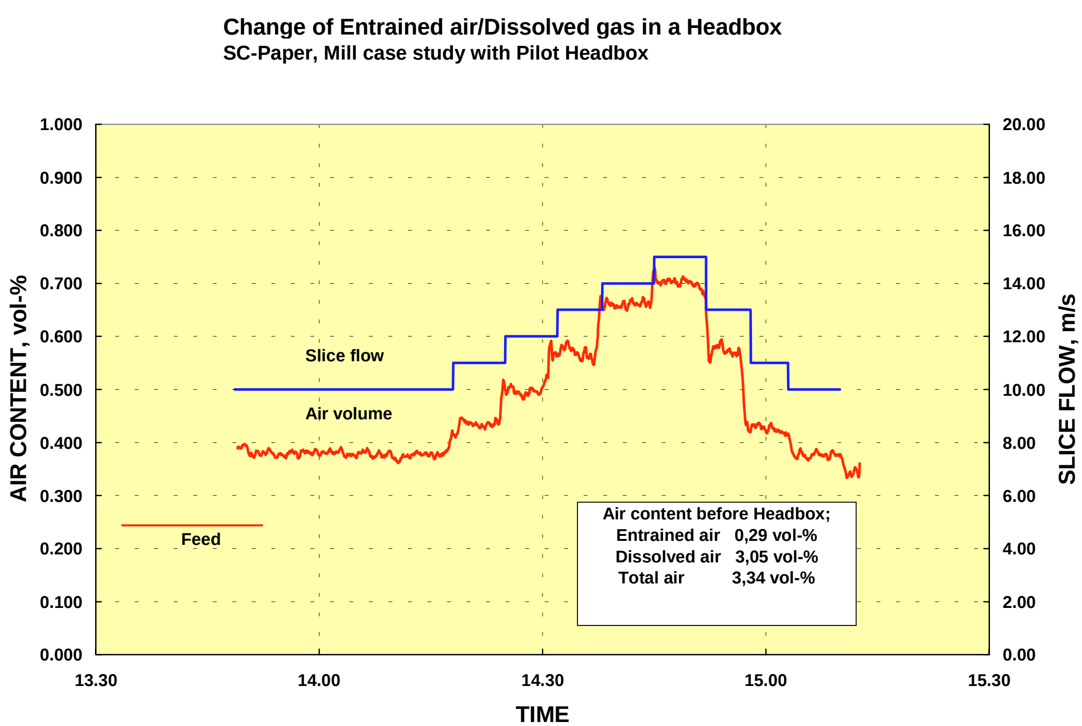



*Fig. 11. Variation in entrained-air content in the headbox with change in slice flow for the machine producing supercalendered magazine paper*

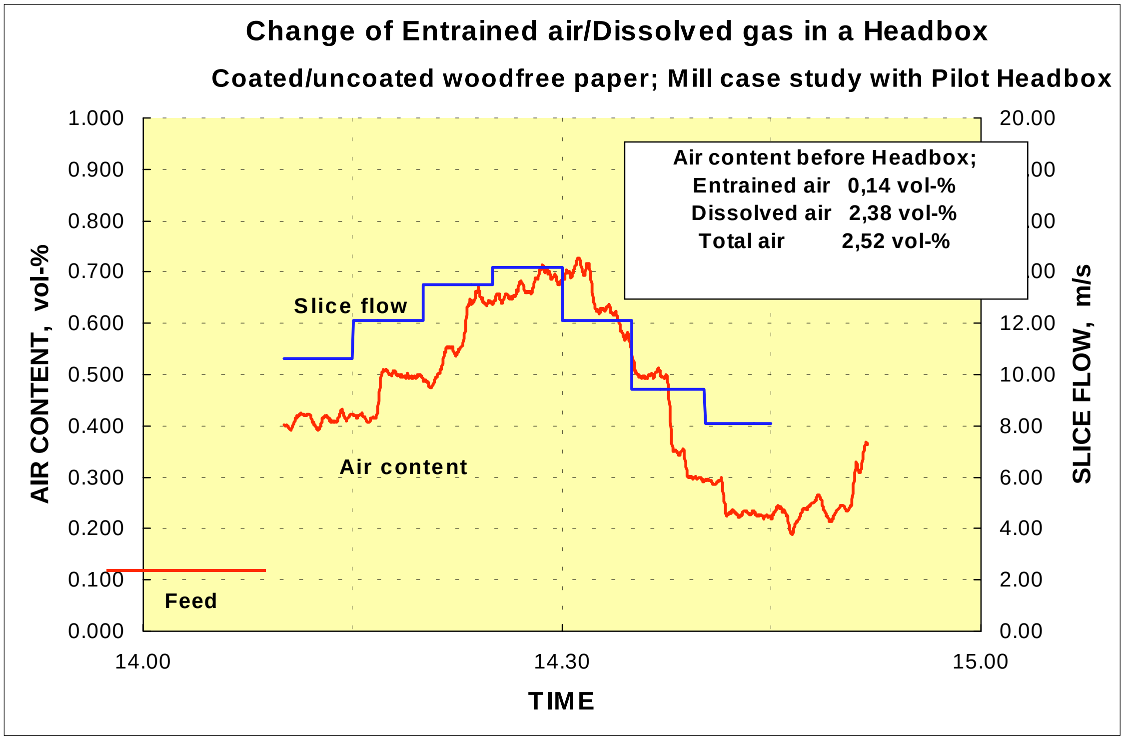



*Fig. 12.* *Variation in entrained-air content in the headbox with change in slice flow for the machine producing wood-free label paper*

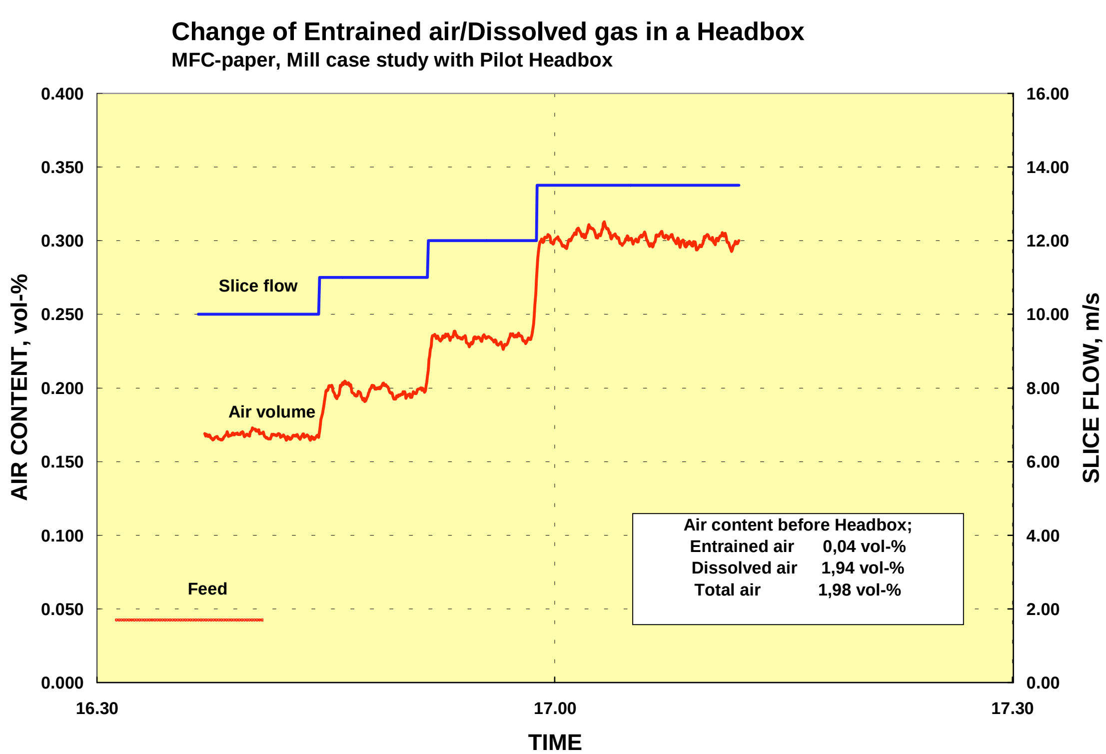



*Fig. 13.* *Variation in entrained-air content in the headbox with change in slice flow for the machine producing matte coated offset paper*

## 4. Air and Gas Balance of the PM Approach System

The entrained air and dissolved gas contents in the PM approach systems were measured and analyzed. By measuring the entrained air and dissolved gases at different stages of the process, and then printing the results on a process-balance sheet, we can easily understand the behavior of air and gases in the process. For example, **Fig. 14** shows the results for PM6 (supercalendered magazine paper), equipped with an efficient PM approach system. A complete deaeration is achieved in the stock prior to the headbox. Stepwise changes take place with equipment in various locations. **Figure 15** shows the result from PM4 (matte coated offset paper), a system with poor deaeration: The deaerator releases dissolved gases into entrained air bubbles. Since there is an inefficient vacuum system and a short air-removal capacity, only a little air can be removed, and the majority will continue with the stock to the headbox.

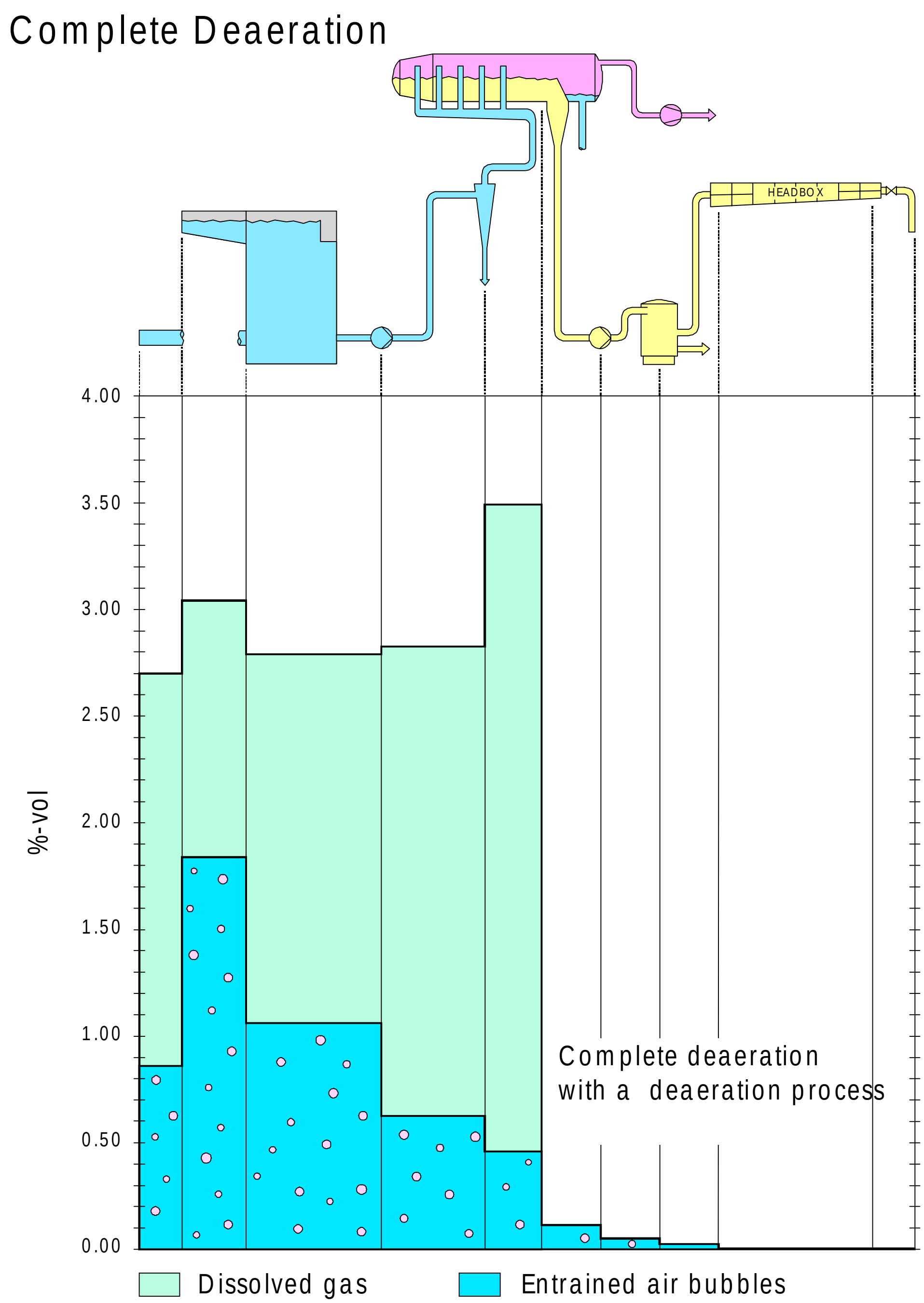



*Fig. 14. Air–gas balance in PM approach system with efficient deaeration (supercalendered magazine paper)*

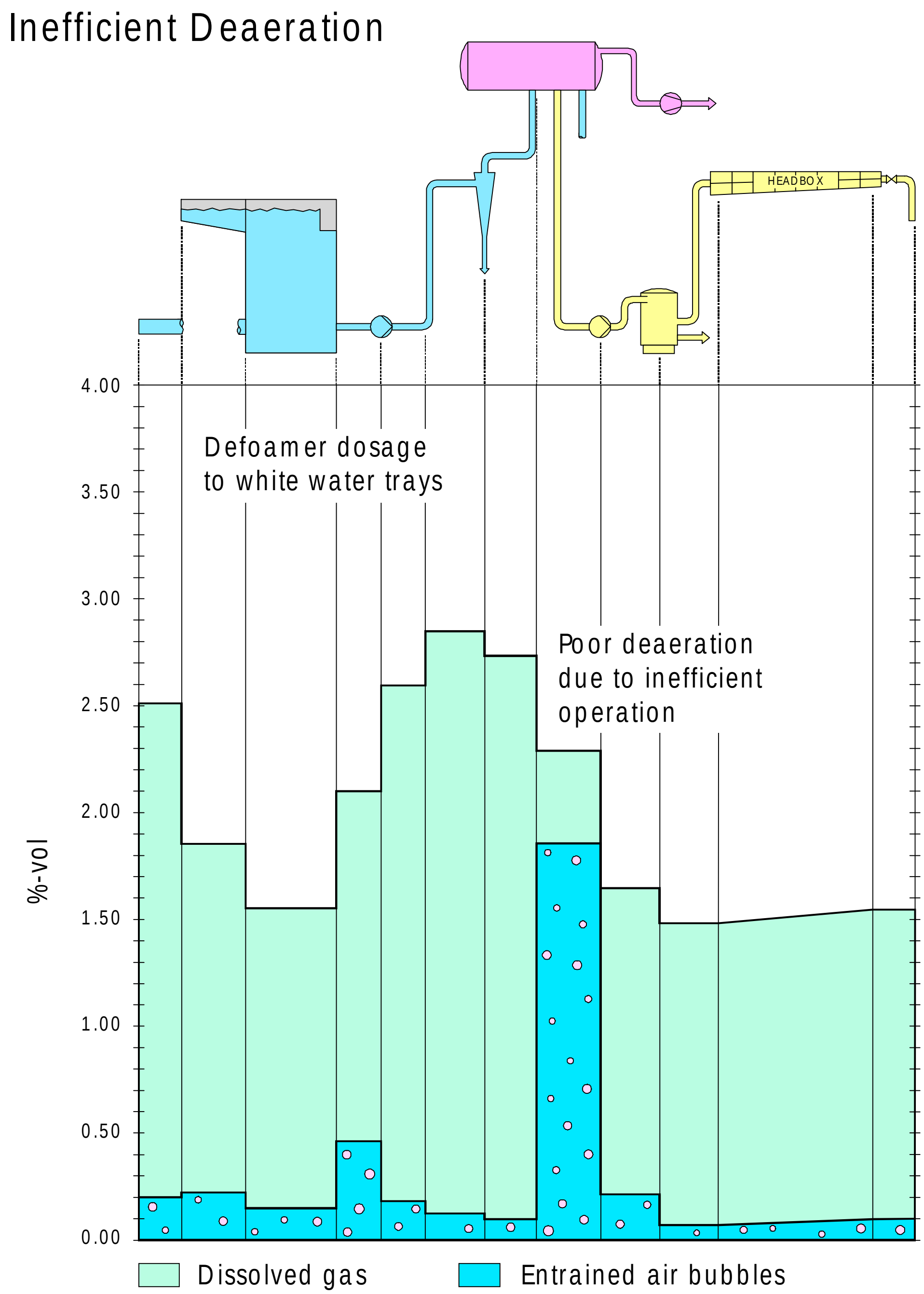



***Fig. 15.** Air–gas balance in PM approach system with inefficient deaeration (matte coated offset paper)*

**4.1 Defoamers and deaeration**

A complete deaeration of entrained air is achieved with a physico-mechanical deaeration process. This means that the stock suspension is strongly undersaturated with dissolved gases and there is no entrained air in the slice flow.

PM3 (wood-free label paper) did not have any physico-mechanical means to remove entrained air. The process consumed a considerable volume of defoamer chemical. The entrained-air content of the stock prior to the headbox was relatively low: 0.1–0.2%, whereas the dissolved gas content was high and the total air content exceeded 2%. With the pilot headbox, it was demonstrated that part of the dissolved gases turned to air bubbles in the headbox. This reduced the operative capacity of the machine.

The process with no deaeration at all is presented in **Fig. 16**. There is a heavy consumption of defoamer chemical. Due to this, the entrained-air content is relatively small and the dissolved gas content high. The total air content is more than 2 vol.%. With the pilot headbox, it was demonstrated that part of the dissolved, saturated gases were released into entrained air bubbles.

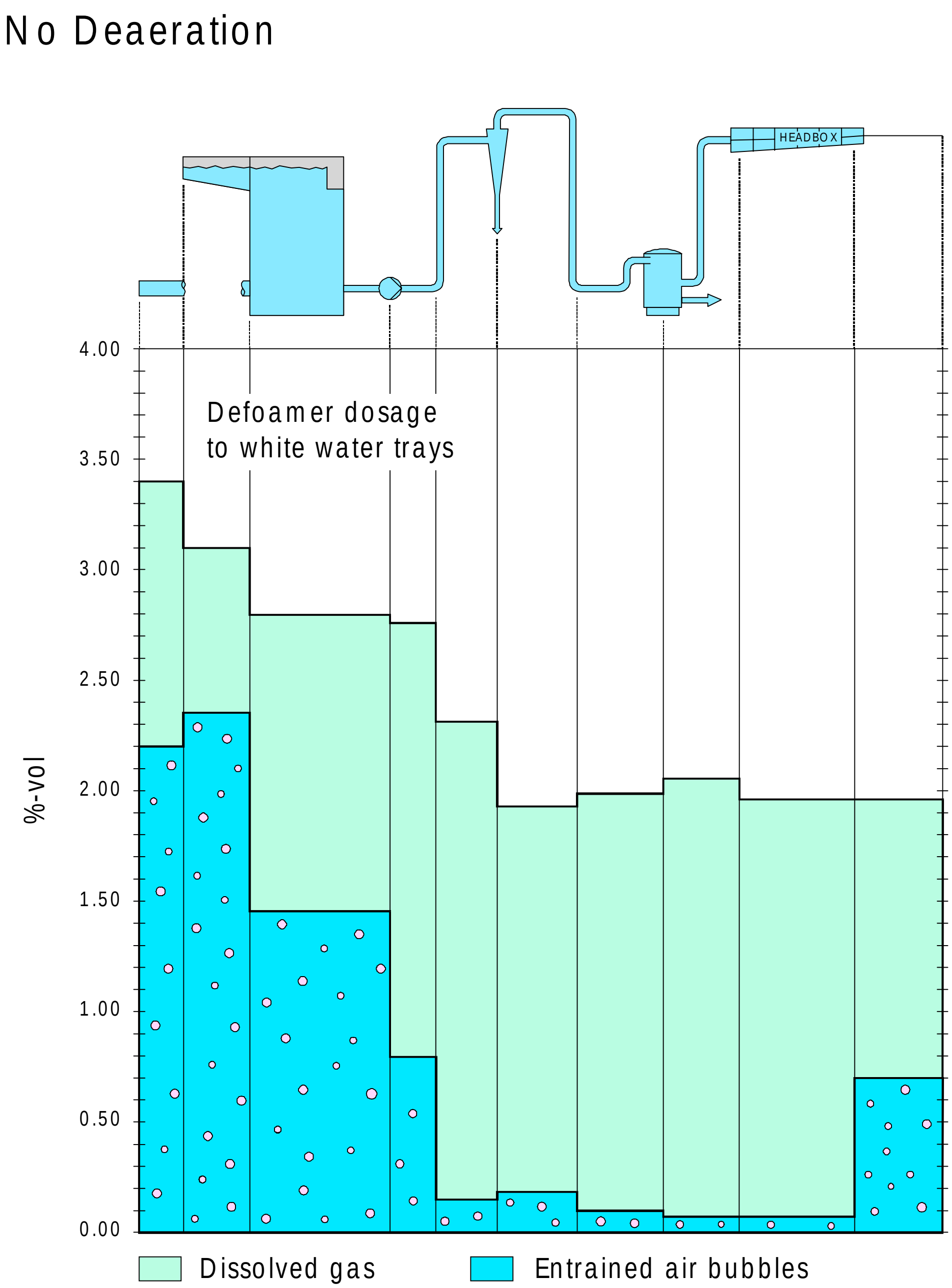



*__Fig. 16.__ Air–gas balance in PM approach system with no deaeration (wood-free label paper)*

**5. Chemicals**

Defoamers can increase the efficiency of the white water silo or wire pit to release excessive entrained air bubbles. The chemical also prevents foam buildup while decreasing the surface tension of water, which results in an increased sensitivity to changes in the balance between dissolved gas and entrained air. **Figure 17** shows that the relative share of dissolved gas increases following an increase of defoamer dosage (matte coated offset paper).

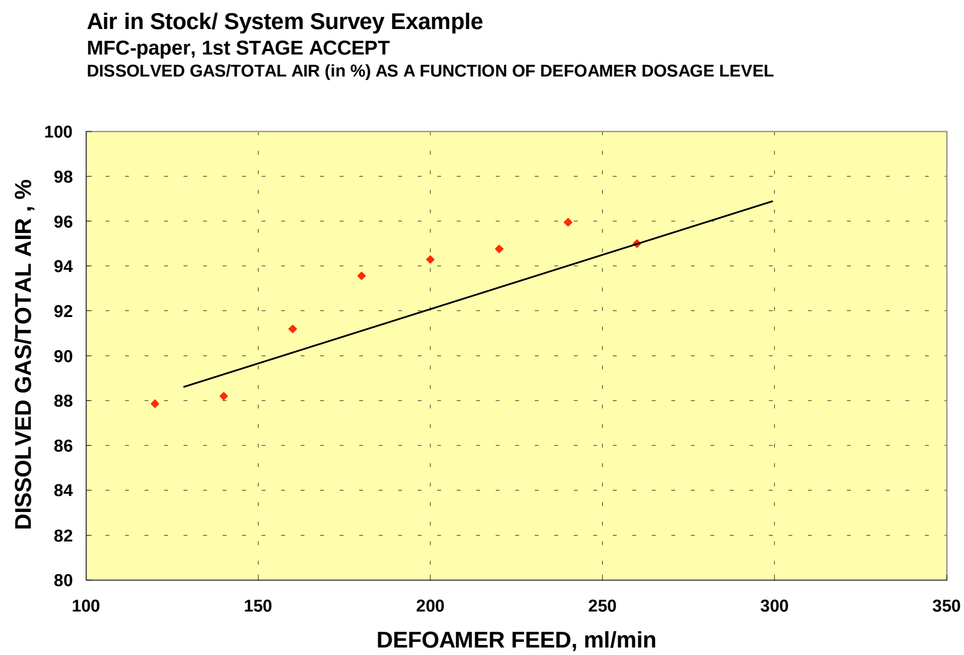



*Fig. 17. Dissolved gas as a function of defoamer dosage (matte coated offset paper)*

Excessive use of defoamers is not recommended, since it can also result in a decreased retention and an increased consumption of retention chemical. It can also increase dirt buildup on the wire fabrics and press felts.

The effect of defoamer dosage on deaeration can easily be followed by monitoring the entrained air and dissolved gas contents after the white water silo. On-line instruments are available to measure entrained air with good accuracy. In many cases, it is possible to find the ideal defoamer dosage level that will give the lowest entrained-air content with the lowest chemical consumption, as seen in **Fig. 18**.

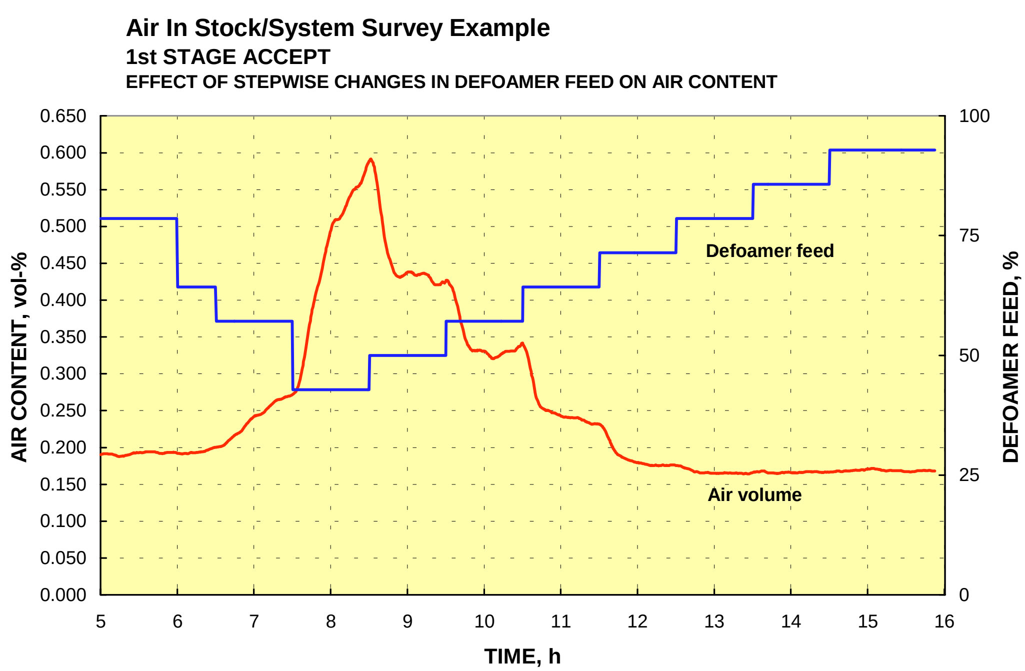



*Fig. 18. Identifying optimum defoamer dosage levels by tracking entrained-air content at various dosages of defoamer*

## 6. Methods Used to Measure Entrained Air and Dissolved Gases

There are several methods for measuring entrained air in the stock. However, most of the methods were found to be ineffective or impractical because they could not measure the dissolved gases [TAPPI UM 653, Entrained Gas Tester (EGT), Process Air Measurement (PAM)]. The methods were based on compression, weight, or density.

### 6.1 Boadway method (expansion method)

The Boadway method was originally developed by J. D. Boadway in the 1950s. Some of the available instruments are based on this principle (Techpap, a manual instrument from France, and the new automatic GasStation™ 100 from Ahlstrom Machinery). The Boadway principle was selected because the method can measure both entrained air and dissolved gases with reasonable accuracy.

The principle is based on the fact that water and fibers show very little or no expansion or contraction with the pressure changes, while gas and air in the bubble state will expand or contract with such changes. The Boadway method is sometimes also called the "expansion method," since the stock sample is brought under vacuum and air or gas bubbles expand and grow larger during the measurement.

Principle of the method: A sample is taken from a stock line, and a fixed volume of stock is isolated in a sample chamber under atmospheric pressure. A sudden vacuum is applied to the sample. Following Boyle's law, the air or gas in the sample expands under the vacuum. By measuring the increase of the sample volume, the entrained-air content can be accurately determined. By extending the effective measurement time under the vacuum, dissolved gases will come out from the solution and form tiny bubbles, thus allowing measurement of the dissolved gas volume too. The dissolved gas content represents the amount of gas that can be released from the stock in the applied vacuum. Typically, the stock contains more dissolved gas than can be measured using this method. The Boadway method shows the amount of dissolved gases that has potential to form entrained air in the process *(3)*.

### 6.2 On-line measurement of entrained air with ultrasonics

An instrument to analyze entrained air on-line continuously has been available for several years (Sonica instrument by Conrex Automation in Finland). The principle of operation of the instrument is based on the fact that ultrasonic energy will attenuate in stock if there are entrained air bubbles present. The more air involved, the greater is the attenuation. The stock is fed via a by-pass line through the instrument. After calibration, the volume of entrained air can be recorded accurately. However, no dissolved gases can be measured. The instrument is especially useful in measuring and following instantaneous changes of the entrained-air content. For example, the instrument can be used to control the dosage of defoamer chemical. The chemical consumption can be optimized by following the entrained-air content.

### 6.3 GasStation™ 100 for measuring entrained air and dissolved gases

Ahlstrom Machinery has recently developed and brought to market GasStation 100, an air and gas measuring instrument. GasStation 100 measures both entrained air and dissolved gases on-line automatically. There is also an optional dissolved oxygen gas analyzer included. Mill experiences are very encouraging.

## 7. Variation of Air Content

The previously described methods and instruments were used to measure local variation of entrained air. The air content in the stock is not a flat, even number. Air volume varies by time, and the content differs by the location in the process. The three tested machines were monitored and measured for air in the process on-line and continuously. Random changes between 5% and 20% of air volume were typically measured before the deaeration, but occasional, much larger (100–200%) fast and slow changes were also detected. A typical result is presented in **Fig. 19**.

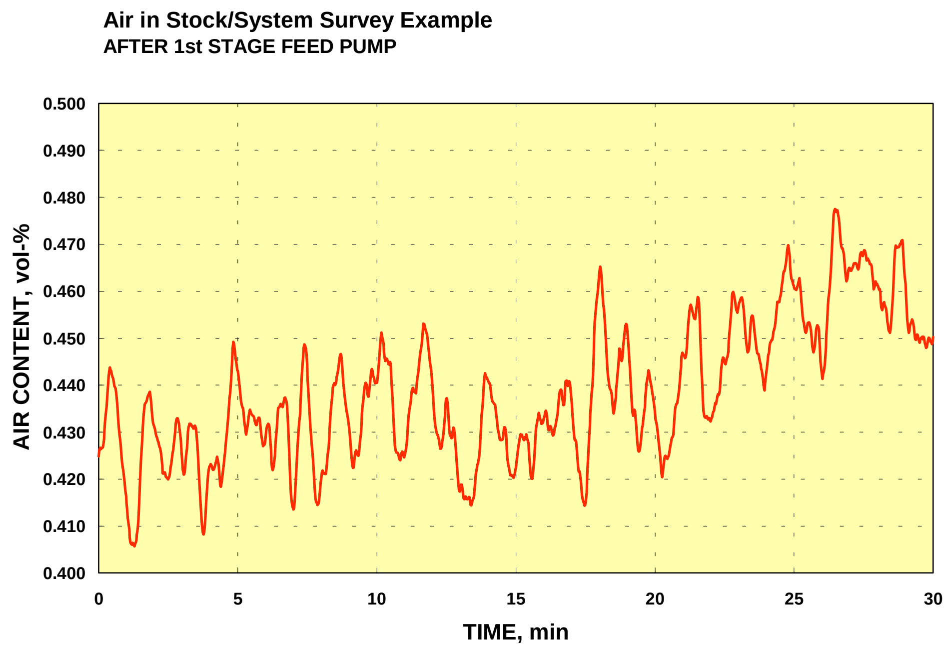



***Fig. 19.*** *Typical results showing random 5–20% variation in air content over time*

Local variation of air in a pipe can be significant if the entrained air bubbles channel in a certain part of the pipe. In the example in **Fig. 20**, the total air/gas content is about the same across the vertical cut in a pipe, but there is more entrained air in the upper part of the pipe and more dissolved gas in the bottom. If the channeling goes all the way to the headbox feed manifold, the entrained-air distribution in the slice flow will have a significant variation. This will result in an uneven drainage on the wire section. A traditional fourdrinier machine will show it as an uneven dry line on the wire.

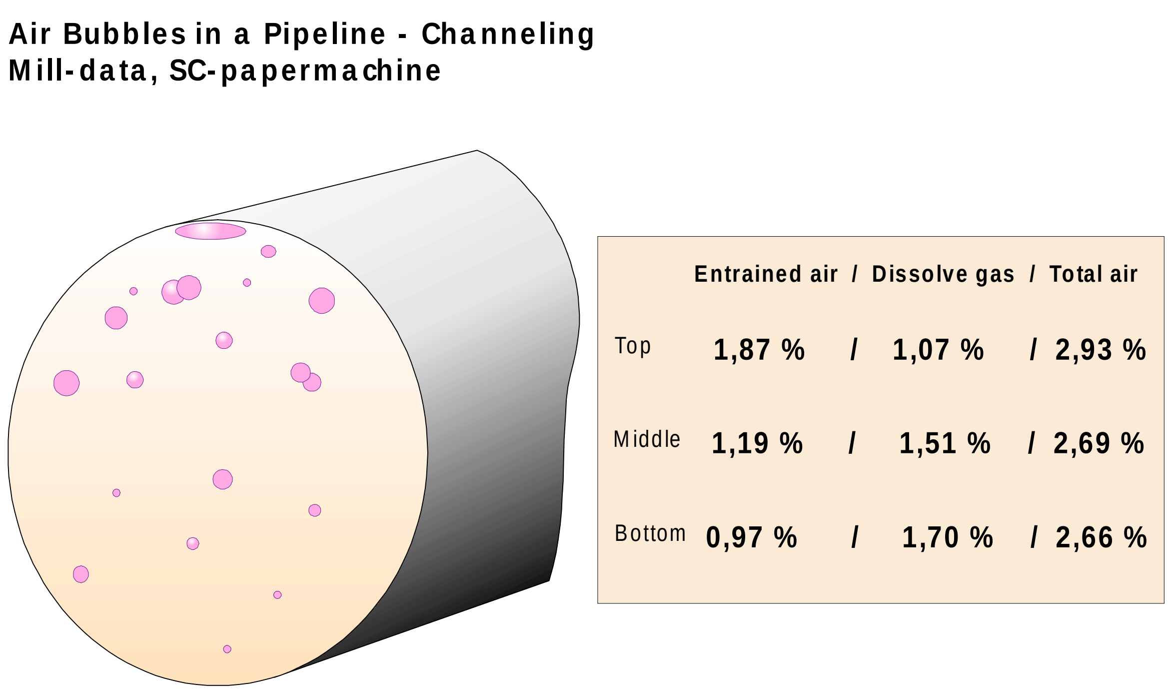



***Fig. 20.*** *Channeling of air flow in a pipe*

The local variation of entrained air also produces a fluctuation in local stock consistency, because the air displaces fibers and water by its volume. Thus a stock containing 2% air has relatively a 2% smaller fiber consistency compared with completely deaerated stock.

**7.1 pH of stock and variation of entrained-air content**

The machine producing matte coated offset paper was operated purposefully with a momentary increase in the entrained-air content prior to the headbox. The stock furnish contains $CaCO_3$, and the $CO_2$ content in the entrained air is more than 20%. It was recorded that a small change of the entrained-air content -- from 0.06% to 0.18% -- changed the pH from approximately 7.18 to 7.11: **Fig. 21**. The pH change is small, and in this case, it has no influence on the actual operation of the process, but larger fluctuations of the entrained-air content can cause a disturbing pH variation.

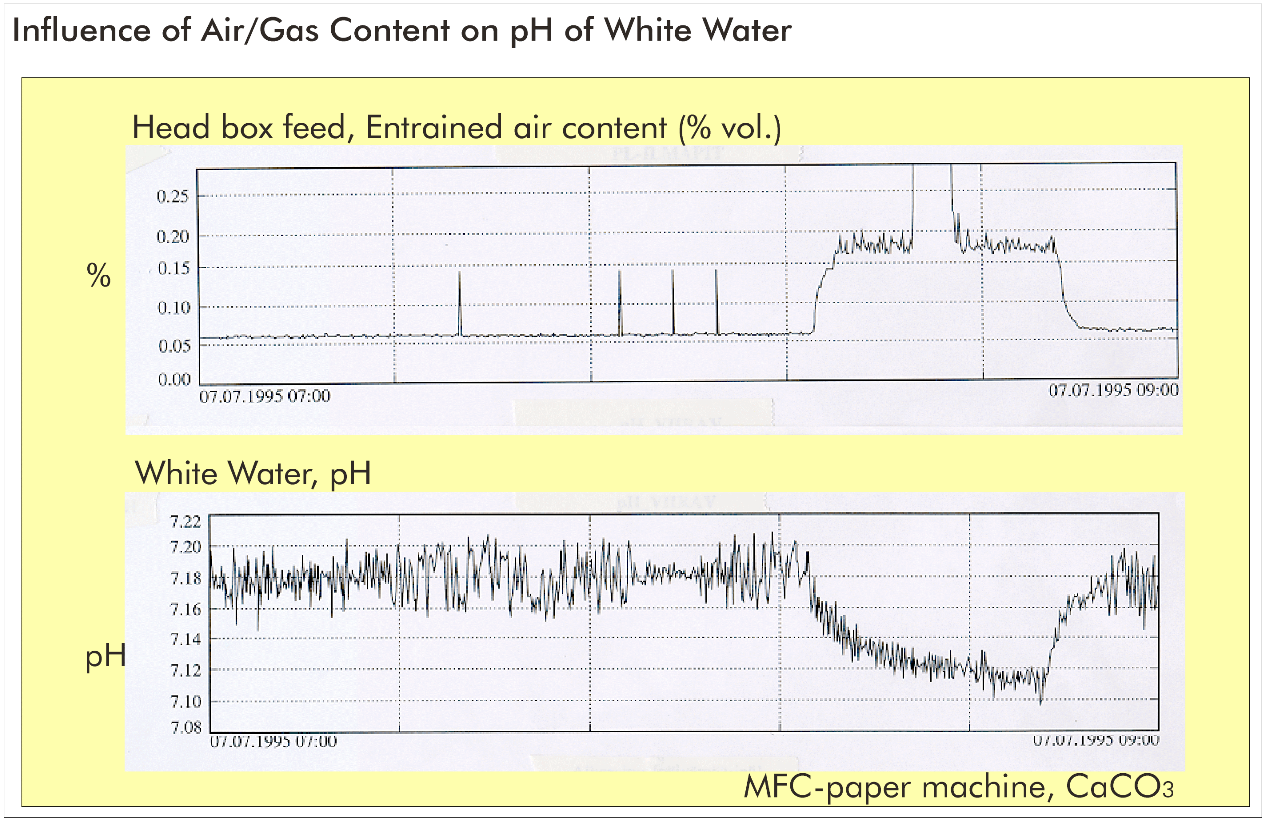



***Fig. 21.*** *Influence of entrained-air content on white water pH (matte coated offset paper)*

**7.2. Influence of air on the operation of the former**

Entrained air has several negative effects on the papermaking process. In addition to the paper machine runnability, the obvious things are drainage on a former, sheet formation, profile, and certain quality items of paper. The headbox of a paper machine delivers the stock onto the wire. In one liter of stock containing 0.5% air, there are ten million tiny air bubbles (approximately 0.1 mm in diameter), which can easily cover and block the openings of the wire fabric, as seen in **Fig. 22**.

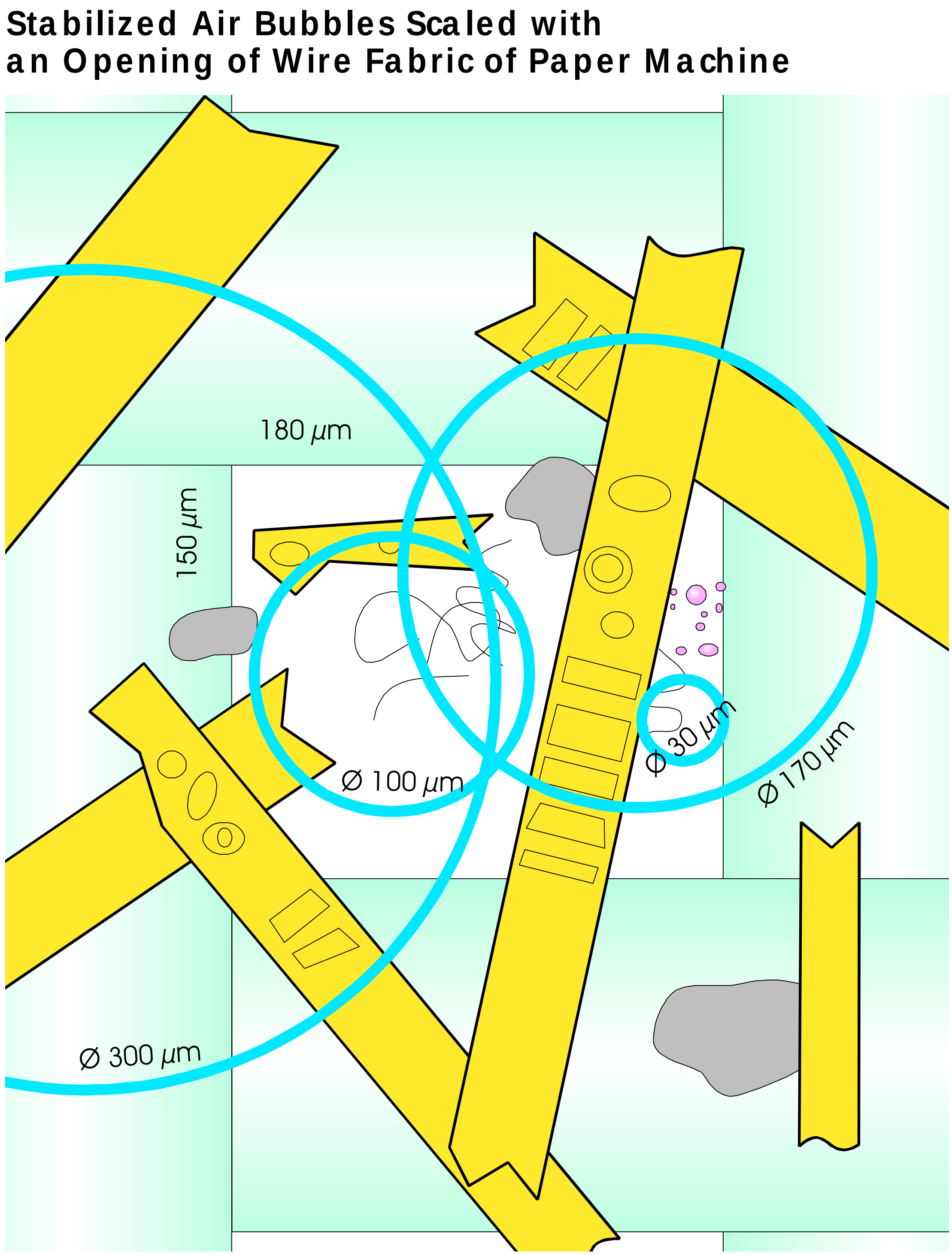
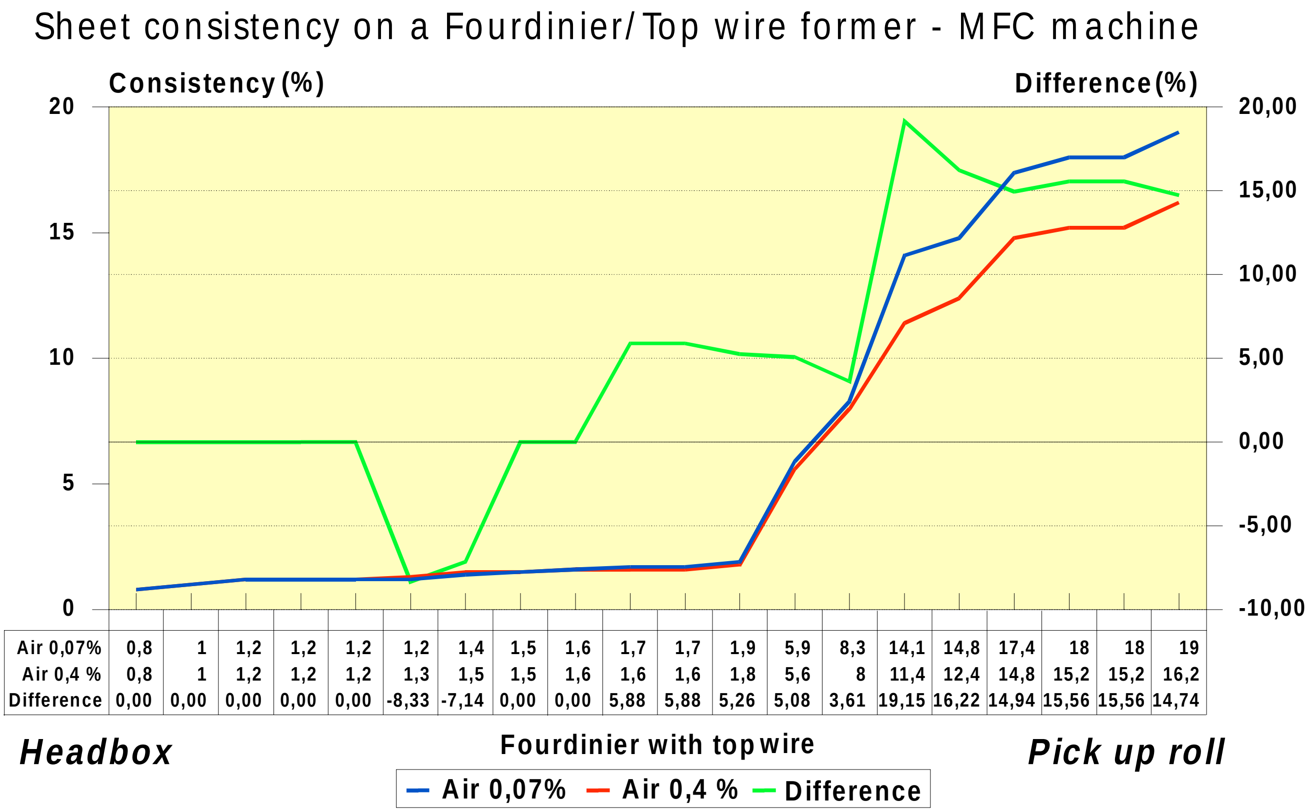



***Fig. 22.*** *Stabilized air bubbles scaled with openings on a typical forming wire*

Drainage/dewatering studies on the wire section were carried out by reducing the deaeration capacity of the MFC machine (matte coated offset paper). This was accomplished by throttling the sealing water to the vacuum system of the deaeration process, and the dewatering profiles were then measured and analyzed. The results are presented in **Fig. 23**. A remarkable difference was detected in sheet consistency off the former. At an entrained-air content of 0.07%, the sheet consistency was 19%. However, when the entrained-air content was allowed to increase to 0.4%, sheet consistency dropped to 16.2%.




| | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Air 0,07% | 0,8 | 1 | 1,2 | 1,2 | 1,2 | 1,2 | 1,4 | 1,5 | 1,6 | 1,7 | 1,7 | 1,9 | 5,9 | 8,3 | 14,1 | 14,8 | 17,4 | 18 | 18 | 19 |
| Air 0,4 % | 0,8 | 1 | 1,2 | 1,2 | 1,2 | 1,3 | 1,5 | 1,5 | 1,6 | 1,6 | 1,6 | 1,8 | 5,6 | 8 | 11,4 | 12,4 | 14,8 | 15,2 | 15,2 | 16,2 |
| Difference | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | -8,33 | -7,14 | 0,00 | 0,00 | 5,88 | 5,88 | 5,26 | 5,08 | 3,61 | 19,15 | 16,22 | 14,94 | 15,56 | 15,56 | 14,74 |

***Fig. 23.*** *Effect of entrained-air content on sheet consistency exiting the forming section (matte coated offset paper)*

**8. Conclusions of the Study**

The various studies at the mill taught that it is very important to know the entrained-air content of the stock as well as the amount of dissolved gases, in order to fully understand what happens in the process. The process must be analyzed from several locations, because the balance of the two forms of air and gas changes, depending on the local circumstances.

White water silo is not necessarily an efficient remover of entrained air. The air removal efficiency can be improved by adding a proper dosage of defoamer chemical into the tray water before the silo. Overdosage should be avoided. The optimum level for the chemical can usually be found by using an on-line analyzer of entrained-air content.

Dissolved gas in the stock can change into entrained air bubbles in a headbox, especially if the dissolved gas content is high or if it is supersaturated. Air bubbles will cause problems on the former and reduce sheet quality. Even small amounts of entrained air in the stock will reduce the drainage capacity of the former and wire section and cause cross-profile variation in the sheet.

Mixing of air and gases into the white water and stock fed to the headbox will cause some severe problems to the process. The origin of the problem and its solution are often hard to find, due to the complicated process with all the mechanics and chemistry involved. Mill management, together with the operators, learns to live with these problems - not by solving them, but by finding a method (often an expensive one) to make reasonable quality despite the existing difficulties. In the course of time, they will probably also accept a lower efficiency or production rate for the process.

Air in the papermaking stock can be a source of trouble, and the problem is sometimes hard to trace. With a complete deaeration - by removing both the entrained air and dissolved gases - these problems can be totally eliminated. Stable and favorable conditions will be achieved to produce good quality paper at high efficiency.

**Literature Cited**

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23 figures
3 tables