Prepared for:

Taco Inc., Cranston RI

Taco air and dirt separator 4903AD-4

Summary: Efficiency of air separation

I. Pothof

Report

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delft hydraulics

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Contents

1 Introduction

This document is a summary of WL report H4187.06 “Taco Pall ring air and dirt separator 4903AD-4, Efficiency of air separation”, outlining the test procedure, test results and practical implications. The test results with sub-saturated water are not summarised.

2 Product description

The Taco air and dirt separator 4903AD-4 consists of a tank, which is installed in the main line of a pipe system (typically a large heating installation of an office building or hospital). The typical location is immediately downstream of the heating component of the system, in order to exploit the low air saturation concentration at this high temperature.

The main objective of the separator is to separate particles (corroded material, dirt) and air bubbles. The operation of the Taco Air Separator is based on a completely new method of separating gases from liquids (water) by means of special packing bodies called Pall Rings. This new method is in turn based on a long existing, well tried procedure in the processing industry for purpose of mixing gasses or separating them from liquids. The use of Pall-rings in HVAC systems is however entirely new and Patented. The operating principle of Pall rings resides in the special properties which these rings possess namely:

- Large Surface Area
- High probability of coalescention and Adhesion
- Low resistance to fluid flow
- Locally low velocities for particle settling

The construction of the Pall ring is such that all fluid is brought in contact with the total surface of the Pall ring that is available for adhesion. Microscopically small air bubbles present in the fluid come to attach themselves to the contact-surface of the Pall ring. Once these micro-bubbles have grown to form larger bubbles, they float upwards and can be separated from the fluid.

Figure 1: Drawing of the separator

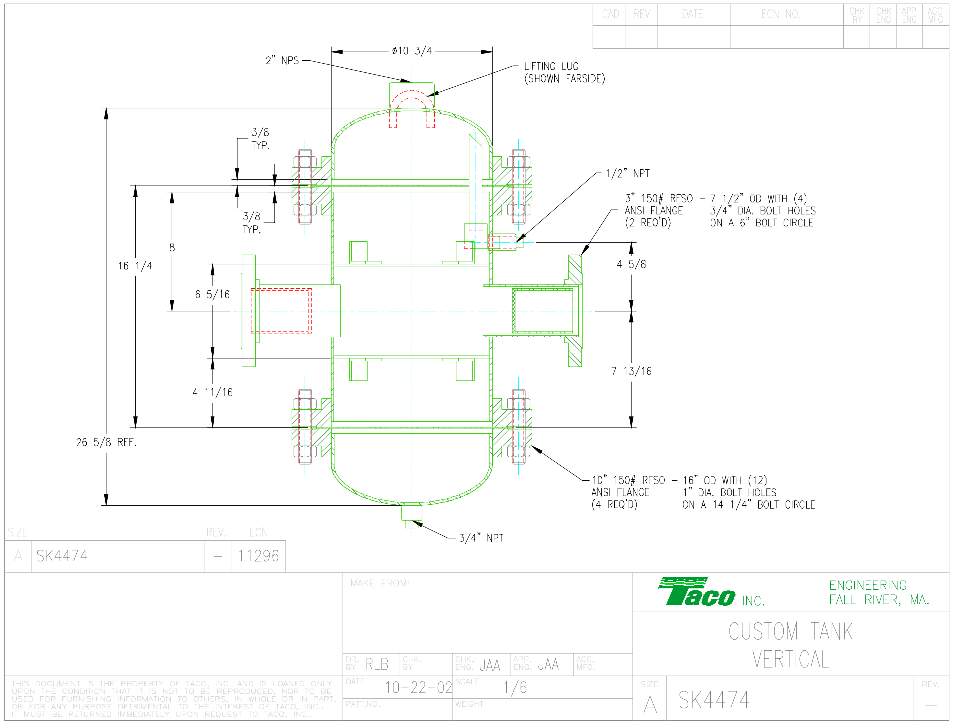


Figure 2: Taco air and dirt separator 4903AD-4 (prototype)

3 Definitions

Dissolved Air	Air in solution in water.
Macro bubbles	Bubbles with a diameter greater than 0.5 mm (visible).
Micro bubbles	Bubbles with a diameter less than 0.5 mm, generally not or hardly visible.
saturated state	The condition of a liquid (water) at a given temperature and pressure when the maximum sustainable amount of a given substance (air) is dissolved in the liquid.
Saturation Concentration	Dissolved concentration at saturated state. The saturation concentration depends on temperature and absolute pressure. In this report the saturation concentration is expressed in ml (air)/ litre (water), where the air volume is the standard air volume at 0°C and 101.325 kPa absolute (1 atm).
Saturation	The actual concentration of a gas mixture (air) in a liquid (water), expressed as a percentage of the saturation concentration at the actual temperature and pressure.
Sub-saturated	If the saturation is less than 100%, then the water is sub-saturated. The water tends to absorb air from bubbles at a certain rate.
Super-saturated	If the saturation is greater than 100%, then the water is super-saturated. The water tends to release air at a certain rate.

4 Test procedure

Overview
A test procedure has been developed which is closely linked to the practical situation of a heating system.

Every time the water passes the boiler, it is heated from 60 °C (140 F) or 70 °C (158 F) to a temperature around 90 °C (194 F). The saturation concentration drops due to the temperature rise, causing the release of dissolved gases. As the temperature drops in the heating system, the saturation concentration rises again, causing free gases to be re-absorbed into the water. Typical saturation changes in the boiler are shown in table 1. It is assumed that the water is saturated at the boiler inlet (low temperature). The saturation at the outlet depends on the inlet concentration and the saturation concentration at the outlet temperature.

Table 1: Overview of typical saturation changes in the boiler

Pressure [bar abs]	T inlet [°C, F]	T outlet [°C, F]	Concentration inlet, [ml/l]	Saturation conc., outlet [ml/l]	Saturation outlet, [%]
3	60, 140	90, 194	33	26	127
4	60, 140	90, 194	45	37	122

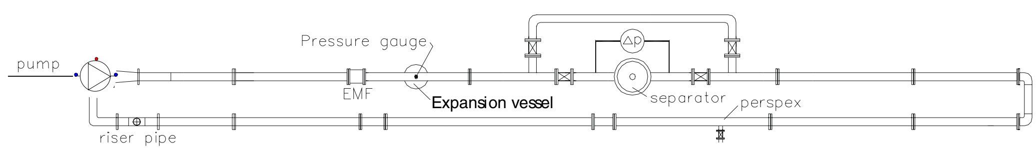
Consequently a typical saturation at the boiler outlet is about 125%, i.e. 25% super-saturated.

The temperature rise cannot be simulated in the circuit. But the situation of super-saturation can be established by means of a certain pressure drop. Since the dissolved air concentration is relatively low in the test water (24 ml/l), the air concentration is first increased through aeration and subsequent venting of free gas. Then the system pressure is quickly reduced to a pressure at which the water is approximately 25% super-saturated. Then samples are extracted and immediately analysed, because the super-saturated water will contain micro-bubbles, that should be measured as well. Therefore the total gas concentration meter, TOLUMET, is directly linked to the circuit.

The water temperature is approximately 15 °C (59 F). A typical test includes a concentration rise through aeration to 57.5 ml/l at 3 bar absolute and a subsequent drop to 2.3 bar abs. The saturation concentration is 46 ml/l at 2.3 bar abs, such that the water has become 25% super-saturated.

The objective of these tests is to determine at which rate developing micro-bubbles, due to sudden super-saturation, are separated by the separator. The decreasing total air concentration, consisting of dissolved air and micro-bubbles, is measured in time.

Test set-up and procedure
The separator is tested in a 50 m long test circuit.



The riser pipe is closed to establish a pressure of 3.0 bar abs.

The TOLUMET is located immediately downstream of the by-pass, extracting samples from the bottom section of the pipe to prevent extracting large air pockets from the top section of the pipe. However micro-bubbles, floating in the pipe will be extracted and measured by the TOLUMET.

Since the saturation concentration is sensitive for both pressure and temperature, especially in the range between 10 °C and 20 °C, the system pressure and temperature are measured (1 Hz), such that the saturation concentration can be computed accurately. Furthermore two expansion vessels with a total gross content of 70 litres are installed to prevent a significant pressure drop due to sampling. the pressure measurements showed that the pressure dropped at most 0.03 bar (1.3%) due to sampling. In order to maintain a constant pressure, the system is replenished with drinking water.

The sample time of the TOLUMET has been set to 20 s, such that approximately 500 ml is extracted from the circuit. On the one hand, this volume is sufficient to flush the analysis container and flexible hose from the circuit to the instrument. On the other hand, the volume is small enough to prevent a significant concentration drop due to replenishment: 10 samples (1% of the system volume) will cause a concentration drop of 0.2 ml/l only.

The analysis time of the TOLUMET is about 5 minutes. Hence subsequent samples cannot be taken with shorter intervals. The number of extracted samples is about 15 before the saturation concentration was reached in the different tests. The samples are extracted after 1 to 100 cycles; 1 cycle is the time to circulate through the system at average flow velocity.

The following tests have been carried out:

- Reference test via by-pass at 1 m/s with macro bubbles initially
- Reference test via by-pass at 1 m/s without macro bubbles initially
- Taco air and dirt separator 4903AD-4 test at 0.5 m/s
- Taco air and dirt separator 4903AD-4 test at 1.3 m/s

The release of dissolved gases from the water depends on:

- the super-saturation, created by a pressure drop in the test and by a combination of temperature increase and pressure drop in reality.
- the presence of adhesion nuclei, such as PALL rings and existing bubbles.

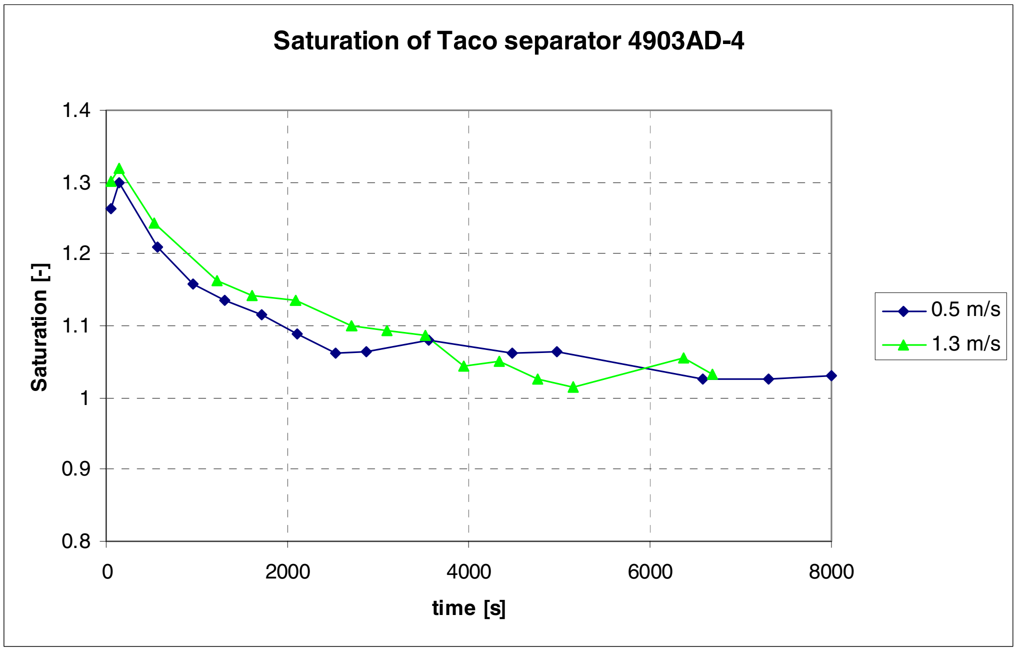
5 Test results

The measured concentration in the first reference test without the separator drops more quickly than in the reference test without macro bubbles. This observation confirms that the presence of bubbles stimulates the release of dissolved gases. The measured concentration drops in about 75 cycles to the saturation concentration in the second reference test, with the disadvantage of bubbles in the system.

If the system is brought to a super-saturated state, then the Taco air and dirt separator 4903AD-4 immediately separates developing macro bubbles. The separator collects the macro bubbles on the PALL rings, instead of leaving the macro bubbles throughout the system, so that most of the release of dissolved gases and micro bubbles occurs in the separator; this process is stimulated by the PALL rings.

The rate at which the saturation drops is comparable for the 0.5 m/s and 1.3 m/s tests. The saturation drops in about 6000 s (38 cycles @ 0.5 m/s and 100 cycles @ 1.3 m/s) to the saturation concentration (see figure 1). The saturation drops exponentially to the saturation concentration at the location of Taco separator. If the Taco separator is installed at the location with the lowest saturation concentration—typically after the boiler—, then the air concentration will become sub-saturated in the rest of the system.

Figure 1: Evolution of saturation of Taco air and dirt separator 4903AD-4



6 Conclusions and practical implications

It is assumed that the air concentration in the filling water of the heating system is greater than the saturation concentration at the boiler outlet. Dissolved air is converted to free gas at the location in the heating system where the saturation concentration is at its minimum; typically at the boiler outlet, where the separator ideally is installed. As the system temperature drops, the saturation concentration rises and free gas is re-absorbed in the system water. Therefore, the process of conversion to free gas occurs in the vicinity of the separator only. This process is strengthened if gas bubbles are present already, like in the Taco air and dirt separator 4903AD-4.

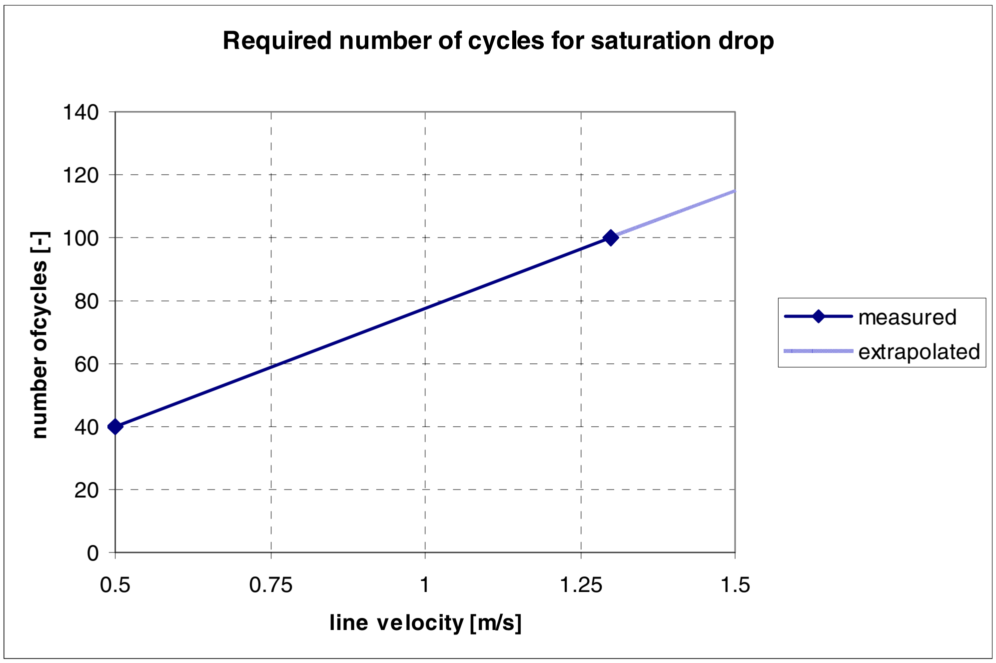
Based on the test results, the Taco air and dirt separator 4903AD-4 reduces the air concentration in the heating system to the saturation concentration at the position of the Taco air and dirt separator 4903AD-4. This takes approximately 40 cycles @ 0.5 m/s and 100 cycles @ 1.3 m/s. Extapolation yields 115 cycles @ 1.5 m/s; see figure 2.

In a heating system without a Taco air and dirt separator 4903AD-4 the air concentration will drop to the ***maximum*** saturation concentration in the system. A further drop is not likely to occur, because the reference tests shows that the air concentration drops slowly towards a saturated state. Should a Taco separator be installed at the preferred location, then the air concentration will drop to the ***minimum*** saturation concentration.

Macro bubbles were absent during the tests with the Taco separator. Hence the process of conversion to free gas mainly occurs in the separator during the tests. Furthermore, the established super-saturation (through a pressure drop) in the tests is comparable in magnitude with the super-saturation due to a temperature rise from 60 °C (140 F) to 90 °C (194 F) at a pressure of 3.5 bar abs. Therefore the tests are comparable with practice regarding the super-saturation and the location of the conversion process to free gas (namely in the separator).

Pressure effects due to elevation and friction in the heating system have not been considered above for comprehensibility. The same reasoning, regarding the saturation and conversion to free air, applies if the Taco separator is installed at a location where the saturation concentration attains its minimum; the optimal location is determined by a combination of pressure (minimum) and temperature (maximum).

Figure 2: Required number of cycles at different separator line velocities (1 m/s ≅ 3.28 ft/s)



If the Taco air and dirt separator 4903AD-4 is installed at the location where the saturation concentration attains its minimum, then the air concentration is lower than the saturation concentration in the rest of the heating system. Hence the saturation drops below 100% (sub-saturation) in the rest of the heating system. Air pockets in the rest of the system can be re-absorbed into the system water, to be released on passing through the Taco separator. When all air pockets have been removed, the saturation remains less than 100%. An example is shown in table 2 and figure 3.

It is recommended to operate a heating system after (re)filling temporarily (100 cycles) at the highest feasible temperature and the lowest feasible pressure in order to maximise air separation by the Taco air and dirt separator 4903AD-4.

Table 2: Typical system saturations

Taco separator location			System location with maximum saturation concentration			Saturation	Sub saturation
T [°C]	P [bar abs]	C-sat [ml/l]	T [°C]	P [bar abs]	C_sat [ml/l]	[%]	[%]
90	3.5	32	60	3.5	39	82 (=32/39)	-18
90	2.0	14.5	60	2.0	21	69 (=14.5/21)	-31

Figure 3: Saturation drop at system location for the typical situation of table 2, second row, at 1.3 m/s (limit value is 69%)