DESIGN GUIDELINE DS211

DISSOLVED AIR FLOTATION

FOREWORD

The intent of Design Standards and Design Guidelines is to specify requirements that assure effective design and delivery of fit for purpose Water Corporation infrastructure assets for best whole-of-life value with least risk to Corporation safety and service standards. Design standards and guidelines are also intended to promote uniformity of approach by asset designers, drafters and constructors to the design, construction, commissioning and delivery of water infrastructure and to the compatibility of new infrastructure with existing like infrastructure.

Design Standards and Guidelines draw on the asset design, management and field operational experience gained and documented by the Corporation and by the water industry generally over time. They are intended for application by Corporation staff, designers, constructors and land developers to the planning, design, construction, and commissioning of Corporation infrastructure including water services provided by land developers for takeover by the Corporation.

Nothing in this Design Standard diminishes the responsibility of designers and constructors for applying the requirements of the Western Australia's Work Health and Safety (General) Regulations 2022 to the delivery of Corporation assets. Information on these statutory requirements may be viewed at the following web site location:

[Overview of Western Australia's Work Health and Safety (General) Regulations 2022 (dmirs.wa.gov.au)](dmirs.wa.gov.au)

Enquiries relating to the technical content of a Design Standard or Design Guideline should be directed to the Principal Engineer, Water Resource Recovery, Engineering. Future Design Standard and Guideline changes, if any, will be issued to registered Design Standard and Guideline users as and when published.

Head of Engineering

This document is prepared without the assumption of a duty of care by the Water Corporation. The document is not intended to be nor should it be relied on as a substitute for professional engineering design expertise or any other professional advice.

Users should use and reference the current version of this document.

DISCLAIMER

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REVISION STATUS

This Guideline was developed by Derek Wilson (EBU-ADV-WRR).

The revision status of this Guideline is shown section by section in the table below.

SECT.	VER. /REV.	DATE	PAGES REVISED	REVISION DESCRIPTION (Section, Clause, Sub-Clause)	REVIEWED	APPROVED
REVISION STATUS						
1	1/0	30/09/22	All	New Version/Revision	Derek Wilson	Derek Wilson
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1 SCOPE AND GENERAL

1.1 Purpose

The Corporation has developed a suite of Design Standards and Guidelines. Designers shall comply with these Standards and Guidelines for the definition, design and specification of water services assets being acquired for the Corporation.

The purpose of the Design Standards and Guidelines is to provide:

a) Standards and guidelines applicable in the design of Corporation assets,

b) Explanatory or specific design information, and

c) Information relating to the Corporation preferences and practices which have evolved from more than 100 years of water industry experience.

1.2 Scope

This Design Guideline is focussed on the design of Dissolved Air Flotation (DAF) Units for thickening of municipal Waste Activated Sludge (WAS). It also includes relevant information on DAF for clarification (typically in drinking water applications, algae removal from waste stabilisation pond systems or tertiary polishing of treated wastewater), as well as brief comments on DAFF (Dissolved Air Flotation and Filtration).

The overall intent of the Guideline is to provide clear direction on how a DAF system and its various process elements should be defined to meet a specific performance target and provide trouble-free, low-maintenance operation for the life of the system.

1.3 Design Process

The design process to be followed by Designers is documented in the Corporation's Engineering Design Process and applicable Design Standards.

1.4 Standards

All materials and workmanship shall comply with latest revisions of the relevant codes and standards.

Water Corporation Strategic Product Specifications (SPS), or in their absence the latest editions of Australian Standards, or Water Services Association Australia (WSAA) Codes, shall be referenced for design and specification. In the absence of relevant Australian or WSAA Codes, relevant international or industry standards shall be referenced

In the event of conflict between standards or codes, the following hierarchy shall be used:

1. Statutory requirements of Australia and the State of Western Australia.

2. Water Corporation Strategic Product Specifications, design and construction standards.

3. Australian Standards and Codes of Practice, or Water Services Association Australia (WSAA) Codes.

4. Other international standards or codes acceptable to Australian statutory authorities.

5. Alliance preferred alternative international standards or codes acceptable to Australian statutory authorities as described above.

6. Original Equipment Manufacturers (OEM) design standards.

1.5   Referenced Documents

Documents referred to in this Design Guideline are listed in Appendix A of this Guideline.

For Corporation Standards refer to Section 7 of DS30-01 Glossary - Mechanical.

For Australian and International Standards refer to Section 8 of DS30-01 Glossary - Mechanical.

1.6   Mandatory Requirements

The use of the imperative "shall" denotes a mandatory requirement. Use of verbs other than "shall" such as "will", "should", "may" indicates recommended practice.

1.7   Nomenclature

The symbols listed below relate specifically to design calculations for DAF systems.

A_n	area of nozzle opening(s) in recycle	m^2
A_{cf}	cross flow area from contact to separation zone	m^2
A_{cz}	minimum area of the contact zone	m^2
A_{sz}	minimum area of the separation zone	m^2
A_s	saturator cross sectional area	m^2
a_s	dimensionless air-to-solids mass ratio	kg/kg
a_p	excess air concentration	mg/L
C	required air <u>mass</u> concentration (clarification DAF)	mg/L
C_d	injection nozzle discharge coefficient - 0.61 to 0.64 (typically)	-
h_n	head loss across injection nozzle	m
C_F	float-layer solids concentration	%
d_b	float-layer depth below the water level	m
d_c	clarification depth (min. 0.5m clear water below d_b)	m
d_w	float-layer depth above the water	m
G	(G-value) root-mean-square velocity gradient	s^{-1}
HL_{cz}	hydraulic loading on contact zone	m/h
HL_{sz}	hydraulic loading on separation zone	m/h
H_{cz}	height of the contact zone	m
$K_1 - K_8$	empirically determined constants for a particular raw water	-
L	effective length or perimeter that scraper travels	m
n	number of injection nozzles	
P_{sat}	saturator gauge pressure	kPa
Q_i	raw water flow rate to DAF	m^3/h
Q_r	recycle flow rate	m^3/h

r	DAF recycle ratio $(Q_r : Q_i)$	-
SLR_{sz}	solids loading rate on separation zone	$kg/m^2/h$
SS	suspended solids	g/m^3 (mg/L)
SS_{in}	suspended solids in the raw water	g/m^3 (mg/L)
SS_{out}	suspended solids in the underflow	g/m^3 (mg/L)
S_T	solubility constant of air at temperature T	mg/L/kPa
S_{20}	0.242 for atmospheric air	mg/L/kPa
S_{20}	0.219 for saturator air	mg/L/kPa
T	water temperature (degrees centigrade)	°C
t_{cz}	hydraulic residence time in contact zone	s
v	scraper speed	m/min
v_{cf}	cross-flow velocity between contact and separation zone	m/h
v_L	limiting hydraulic loading on separation zone	m/h
Vcz	volume of the contact zone	m^3
W_{CZ}	width of the contact zone	m
η_s	saturator air transfer efficiency	-
θ	sludge age	days

1.7.1 Engineering Definitions and Relationships

Refer to Section 2 of DS30-01 Glossary - Mechanical.

1.7.2 Preferred Terminology

Refer to Section 3 of DS30-01 Glossary – Mechanical and Appendix B of this Guideline.

1.7.3 Abbreviations, Acronyms and Symbols

Refer to Appendix C of this Guideline.

1.7.4 Standard Units and Relationships

Refer to Appendix D of this Guideline.

1.8 Feedback

This Design Guideline is a live document which requires regular review and revision in accordance with changes in associated standards, latest knowledge, operational experience and technology. Users of the Guideline are encouraged to provide feedback on the content to the Senior Principal Engineer - Water Resource Recovery, Advisory Section, Engineering Business Unit.

2 GENERAL CONSIDERATIONS

2.1   Introduction

Dissolved Air Flotation (DAF) is a phase separation process, whereby microscopic bubbles are released from solution when water, supersaturated with air under high pressure, is released under atmospheric conditions to interact with suspended particles in a water body causing the particles to float to the surface.

DAF systems can be designed to operate with or without polymer dosing. Although polymer dosing is covered in this guideline, the guideline does not include the design of polyelectrolyte dosing systems. The Designer is referred to DS213 – sludge conditioning with polymers (to be developed). In addition, it is strongly recommended that vendor input is obtained, with lab scale testing and proving to be carried out to determine the most suitable polymer type and dose rate.

2.2   Advantages of DAF for used water management applications

DAF is widely applicable in all stages of used water management, as outlined below:

- Efficient for turbidity and particle (e.g., suspended solids) removal.

- Results in more economical filter designs downstream.

- Where applied, facilitates a short detention time of about 5–10 min in flocculation tanks for pre-treatment.

- Higher hydraulic loading rates than in most settling processes may be used.

- More efficient than sedimentation in removing low-density floc formed from coagulation of Total Organic Carbon (TOC).

- Efficient for concentration and removal of both primary and secondary scum, particularly when blended with WAS.

- Continuously produces a homogeneously mixed thickened sludge product that is of ideal quality for feeding digesters or mechanical dewatering equipment.

- Achieves significant soluble BOD / COD reduction in the DAF liquid stream.

- Facilitates reduced coagulant dosages resulting in smaller chemical storage and less sludge.

- Improved algae removal and cold-water performance.

- Less sensitive to flow variations.

- Process flexibility through air loading.

2.3   Applications

DAF is used for the separation of solids from water. It may be used for ***thickening*** or for ***clarification***, and in some instances for both.

Conventionally phase separation is achieved by sedimentation, but sedimentation efficiency is limited if suspended solids have a low density and/or have a high organic content. DAF can be used to overcome these difficulties. DAF is also a higher rate process than sedimentation and requires a smaller footprint. In a thickening operation DAF will produce a much higher solids concentration than sedimentation if designed and operated correctly.

The most common use of DAF in the water industry is for ***thickening*** of waste activated sludge (WAS) to reduce the volume of product to be further treated or disposed of.

If used for *clarification*, DAF can:

- assist in tertiary polishing of treated water to remove high suspended solids loads. A coagulant (such as ferric chloride or aluminium sulphate) would normally be used to assist the process. Sometimes polymer is also used.

- be used for the removal of algae from impounded water bodies as part of a potable water treatment train or tertiary polishing of treated water from waste stabilisation pond (WSP) treatment systems. In this instance, it would normally be done in conjunction with a coagulant.

Combined dissolved air flotation and filtration (DAFF) is a good option for the clarification applications noted above. The use of polymer in DAFF applications is not advised as it has the propensity to blind the filter layer.

2.4 Application differences

It is important to understand the fundamental difference between *thickening* and *clarification* applications, and the respective design approaches. Also see table 2.1.

Thickening

In thickening applications, the *emphasis* is on the character (solids concentration) of the *float layer* on the surface of the tank.

High solids capture (at least 90%, and preferably above 95% with or without polymer) remains important, but this is not the main objective. Nevertheless, Water Corporation DAF system consistently achieve over 98% solids capture.

Clarification

In clarification applications, the *emphasis* is on the quality of the *subnatant* drawn from the bottom of the tank.

High solids capture is important, but the *solids concentration* achieved in the float layer on the surface is of secondary importance.

Clarification and Thickening

When it is important to achieve both good thickening and clarification, it may be achieved with DAFF. In this case, employing a scraper system for the float is optional, as the float can be removed whilst backwashing the filter.

Clarification	Thickening
Main aim is clarity	Clarity less important
Float layer concentration less important	Main aim is concentration of float layer
Design mainly based on hydraulic loading	Design mainly based on solids loading

Table 2-1: Comparison between clarification and thickening operations

Figure 2.1 is an image of a DAF facility for thickening of WAS.

See Nexus: 126115966 for a video of a thickening DAF scraper system.

Figure 2-1: Image of thickening DAF showing DAF tank, scraper system, recycle pumps and saturator system

2.5   Components of DAF systems

Although there are different applications, the main components of DAF systems are the same. A short description of the various components is included below.

Contact zone (historically referred to as the reaction zone)

In this zone particles (solids), water (liquid) and microscopic bubbles (gas) coalesce to form stable particle/bubble agglomerates which are essential to achieving successful separation.

Chemical pre-treatment

It is sometimes necessary to alter the nature of the particles through coagulation and/or flocculation in order to achieve successful separation. Pre-treatment units are "add-on" facilities to DAF systems which aid in improving treated water quality and/or solids concentrations. Design is often carried out ignoring these in the initial phase, and their impact determined through pilot trials or reference to other precedents.

Bubble production system

This system comprises the abstraction and pumping of treated water (DAF subnatant) (the recycle stream) through a pressurised air saturation system, and injection of the supersaturated water into the contact zone.

The bubble production system consumes practically all the energy required to operate a DAF unit, so its economic design is important. Recycle rates should therefore be kept as low as possible to achieve the desired results.

The bubble production system includes a compressor(s) to provide the compressed air for saturation in a saturator vessel.

Separation zone

This is the zone in which phase separation takes place, after the formation of stable particle/bubble agglomerates in the contact zone.

Sizing of this zone depends largely on understanding the relationship between hydraulic loading, solids loading, air requirements and the desired float concentration.

Float layer removal

In general, a scraper system moves thickened sludge to a hopper from where it is withdrawn from the tank - particularly in thickening operations. Various mechanisms and/or approaches are used for this application, each having its own advantages and disadvantages. Good design ensures consistent solids concentration, minimum disruption of the float layer, and minimum impact on the subnatant water. The solids concentration of thickened WAS (without a flocculant) should be at least 3.5% with values of over 4.2% being quite possible in well designed and operated systems. Hydraulic removal of the float layer offers a simpler solution but comes at the cost of increased water loss leading to a larger volume removed and a watery sludge. Hydraulic removal is more common in clarification operations, and particularly so in DAFF operations where unnecessary disturbance of the float layer is a key consideration in avoiding blockage of the filter below. In hydraulic sludge removal operations, the sludge is likely to have a solids concentration of 0.3 to 0.8%, although lower values have been reported from the Netherlands.

Settled sludge removal

A small amount of sludge will always settle, and for this reason a bottom scraper and sludge hopper are built into the bottom of the tank allowing periodic removal of settled sludge.

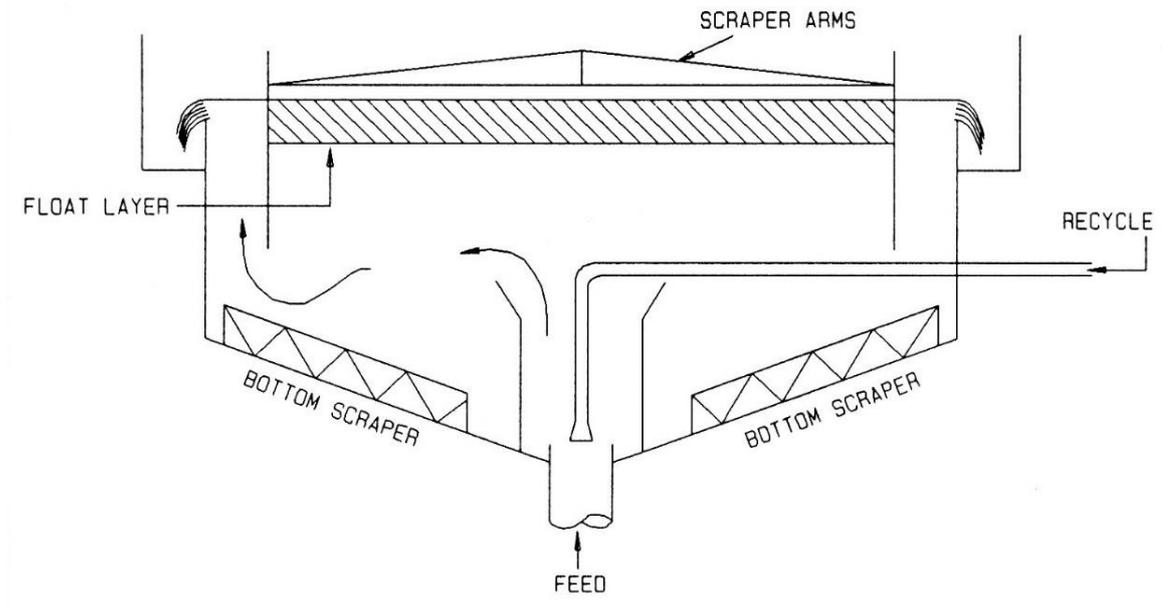## 2.6 Typical cross sections through DAF units

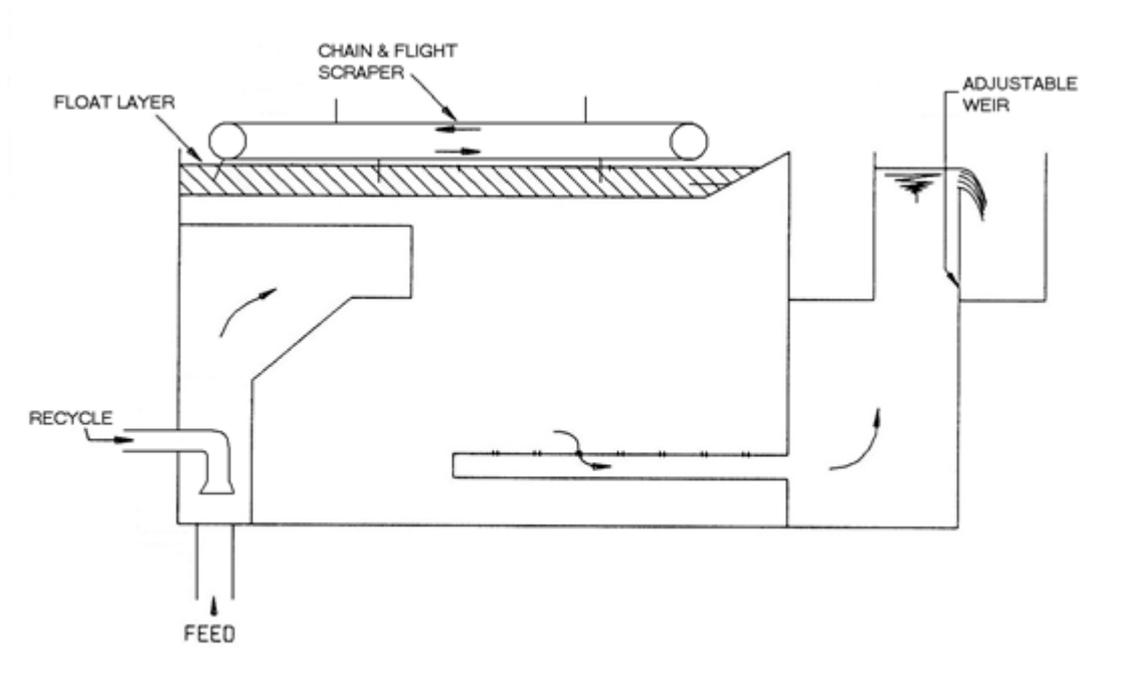*Figure 2-2: Section through circular DAF (Source Haarhoff & van Vuuren, 1993)*

Figure 2-3: Section through rectangular DAF (Source Haarhoff & van Vuuren, 1993)

3 CONTACT ZONE

3.1   General

Feed water and the supersaturated recycle stream coalesce in the contact zone, so named by international convention (1994). Optimum definition of the contact zone is the single most important component in the design of a DAF facility.

DAF is more complex than other phase separation processes because all three phases of matter are involved:

- particles in the solid phase,
- water in the liquid phase, and
- air bubbles in the gas phase.

Stable particle/bubble agglomerates formed in the contact zone then separate in the separation (flotation) zone with the particle/bubble agglomerates floating to the surface and concentrating.

It is necessary to use the correct air/solids ratio (a_s) for specific applications and is best obtained from previous experience. This guideline recommends air/solids ratios for the most common applications (see Table 6.1). The importance of air/solids ratio is discussed further in Section 6.

> **NOTE:**   *The most important factor in design of the contact zone is to limit turbulence*.

3.2   Formation models for air/floc agglomerates

Three models of contact zone air/floc agglomerate formation have been proposed (Figure 3.1).

Model A: Adhesion of bubbles to preformed flocs. This supposes that some level of flocculation has already taken place (as is typical of wastewater WAS), and the bubbles adhere to the particles upon collision. This model will dominate when particles are small, or similar to the bubbles in size.

Particles 20 μm   Bubbles 40 μm

Model B: Mechanical enmeshment of bubbles with preformed flocs. This also supposes that some level of flocculation (typical of WAS) has already taken place, but the particles are much larger than the bubbles. The bubbles tend to 'stick' to the 'jagged' edges of the flocs.

Particles 200 μm   Bubbles 40 μm

Model C: Entrapment or Incorporation of bubbles into growing flocs. This supposes that little or no floc formation has previously taken place. It is based on flocculation in a vertical pipe, with flocculent added after formation of micro-flocs. It requires a high particle concentration, and rapid flocculation.

3.3   Bubble size and coalescence

Bubble size and size consistency are of primary importance for the following reasons:

- There should be at least as many bubbles as particles, because at least one bubble is needed for every particle to be floated. Smaller bubbles mean more bubbles
  - **Note:** one 2mm bubble = 64 000 bubbles of 50μm.
- Smaller bubbles rise slower, and have more time for attachment, leading to more stable bubble/particle agglomerates.
- Larger bubbles rise faster and are more likely to become detached from the bubble/particle agglomerates and cause more hydraulic disturbance as they rise through the contact zone, breaking up other already formed agglomerates in the process.
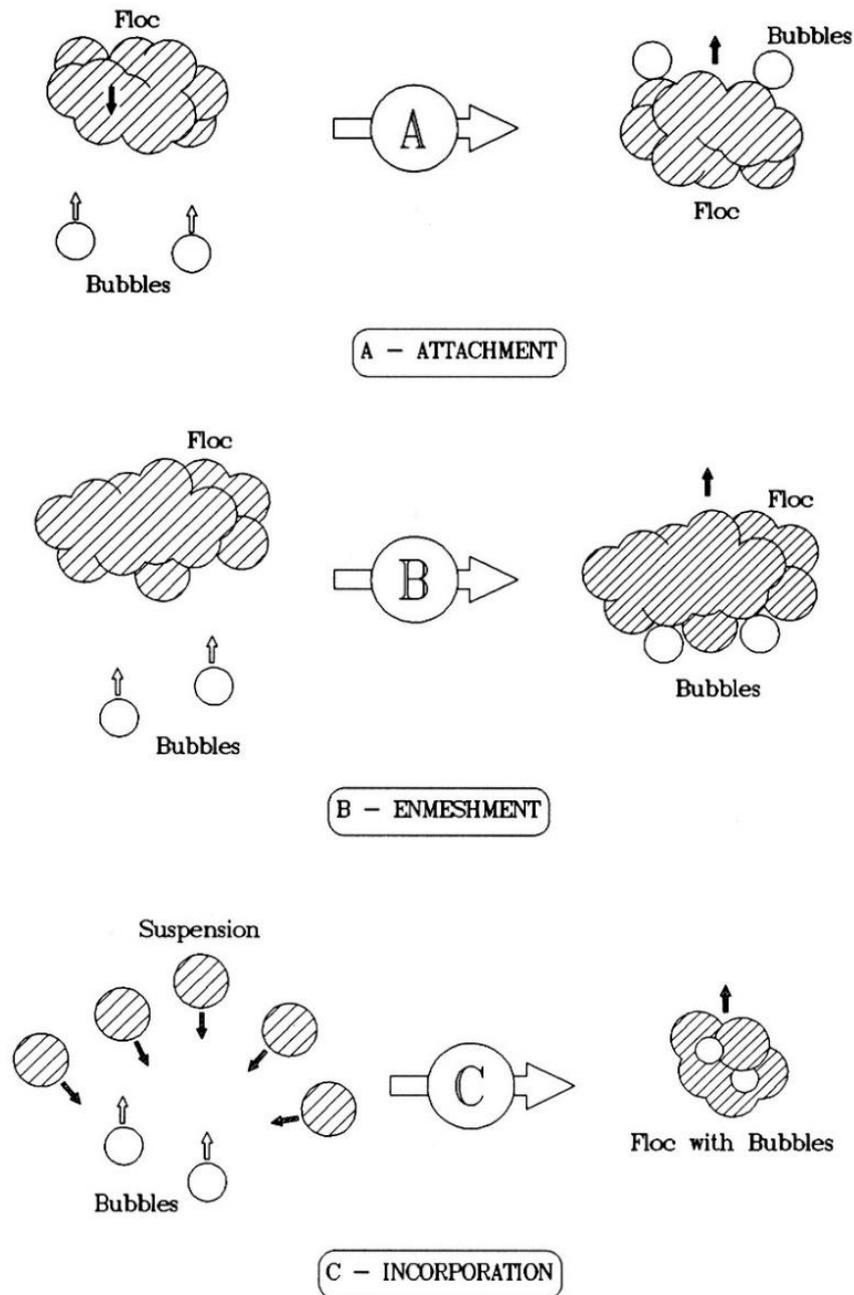
Figure 3-1: Models of agglomerates formation (Source Haarhoff & van Vuuren, 1993)

Average bubble size should be 40 to 110μm to ensure laminar flow. The transition from laminar to turbulent flow occurs with bubbles of about 130μm and larger. Temperature also affects bubble rise rate with the rise rate increasing about 3-fold as the temperature rises from 20ºC to 80ºC for bubbles below 150μm.

Studies have shown that bubbles in the contact zone are generally in the 40 to 80μm size range for effective operation. These studies also showed separation zone bubble sizes to be in the range of 50 to 150μm indicating that a small degree of coalescence does occur. However, every effort must be made to minimise coalescence. In addition to ensuring that the recycle system delivers bubbles of uniform size, any surfaces or structures which have the propensity to aid or promote coalescing must be avoided.

Bubble size is also affected by saturator pressure and the type of pressure release valve. In general, bubble sizes average around 82μm at 200kPa and 62μm at 500kPa.

For the purposes of design, and because this design guide is focussed on WAS which normally requires recycle pressures of about 500kPa, the average size of bubbles in the contact zone is taken to be 60μm and in the separation zone 100μm.

Coalescing of bubbles significantly impacts efficiency. Factors causing increased coalescence include the following:

- High temperature and pressure - increasing pressure does not necessarily lead to better operation – refer to Table 5.1.

- Non-uniform bubbles – larger bubbles pick up smaller bubbles as they rise faster through the contact zone breaking up or preventing the formation of stable bubble / particle agglomerates.

- Violent agitation - a small amount of agitation is required to ensure bubble / particle contact for the formation of agglomerates, but violent agitation will break up the already formed agglomerates.

- Large surface areas - coalescing occurs against such surfaces.

3.4   Particle sizes

These can be expected to be much more variable in size than bubbles and will vary for each application.

Without a coagulant or flocculant, we can assume that:

- Above a certain size, particles become too heavy to be floated, and settle out.

- Below a critical minimum size, particles will not be swept to the surface. These particles tend to remain in suspension and are withdrawn with the clarified water (sub-natant) if they don't settle out.

3.5   Contact zone configuration
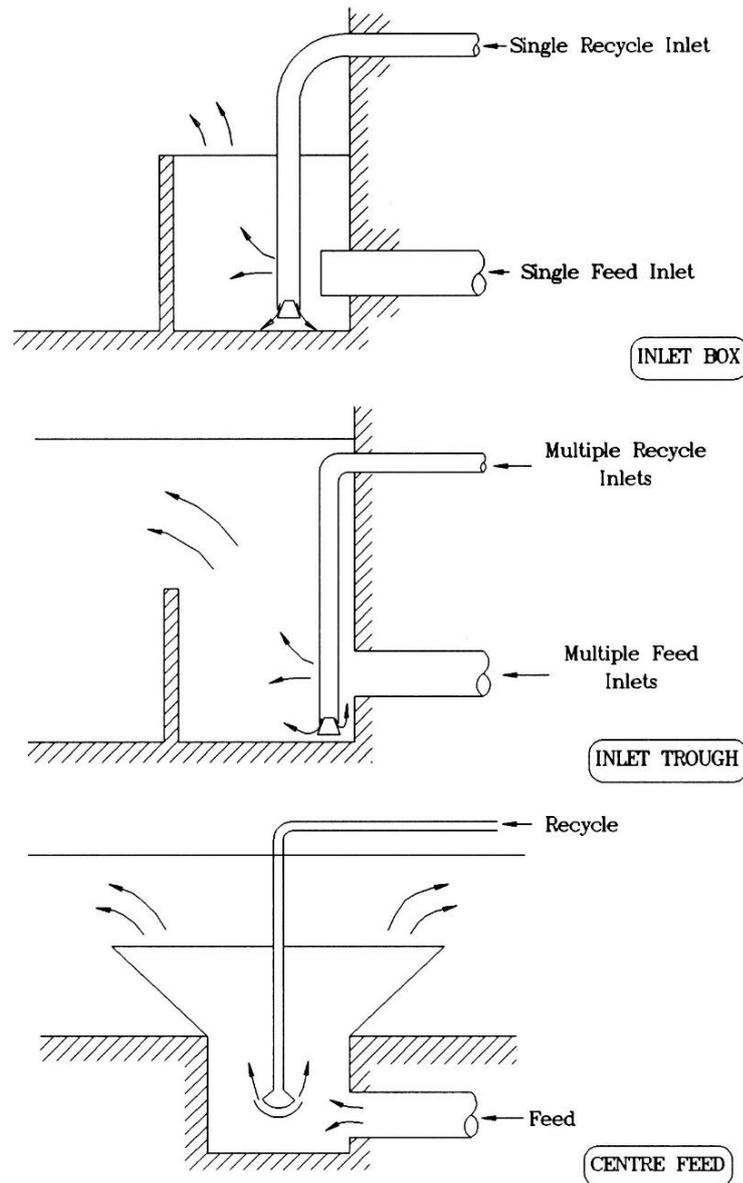
Figure 3-2: Typical contact zone configurations (Source: Haarhoff & van Vuuren, 1993)

> **NOTE:**
>
> ***The most important configuration feature of the contact zone is that the recycle must be released into the feed in the contact zone, and not before.***
>
> *Connecting the recycle stream into the feed pipe outside of the DAF unit is **NEVER ACCEPTABLE.** This is an approach employed by some vendors of circular DAF units because it is easier (and cheaper) than taking the recycle to the centre of the DAF unit and into the contact zone. It causes coalescing to take place in the pipe, which leads to large bubbles rising rapidly through the contact zone, breaking down the floc forming process, and significantly decreasing efficiency of the recycle system by as much as 300%.*
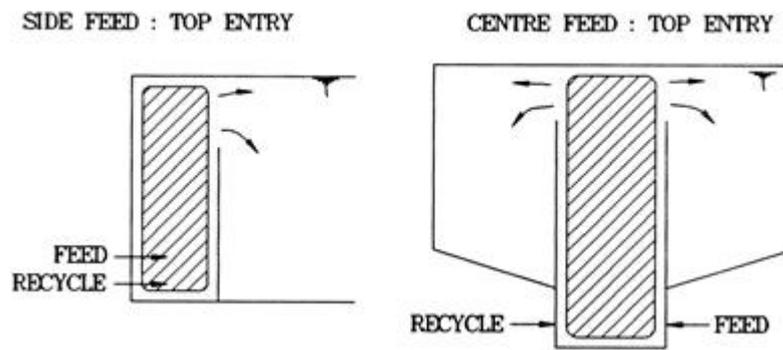
Figure 3-4: Illustration of contact zone definition (Source: Haarhoff & van Vuuren, 1993)

Figure 3.3 shows the extent (shading) of what is defined as the contact zone for rectangular and circular DAF units. Although other configurations have been tried by various agencies, other configurations all present problems relating mostly to high levels of coalescing and breakup of 'already formed' agglomerates.

> *It should be noted that in the case of large contact zones, multiple recycle release points are likely to be required.*

3.6   Contact zone hydraulics

The contact zone should be designed so that residence time distribution (RTD) approaches that of a plug flow reactor (PFR). Some dispersion mixing does occur, but this should be minimised. If mixing is considerable, say due to large bubbles rising rapidly through the matrix, the contact zone will no longer act as a PFR. Achieving plug flow in the contact zone is key to achieving stable particle/bubble agglomerates and ultimately good separation with a high capture rate.
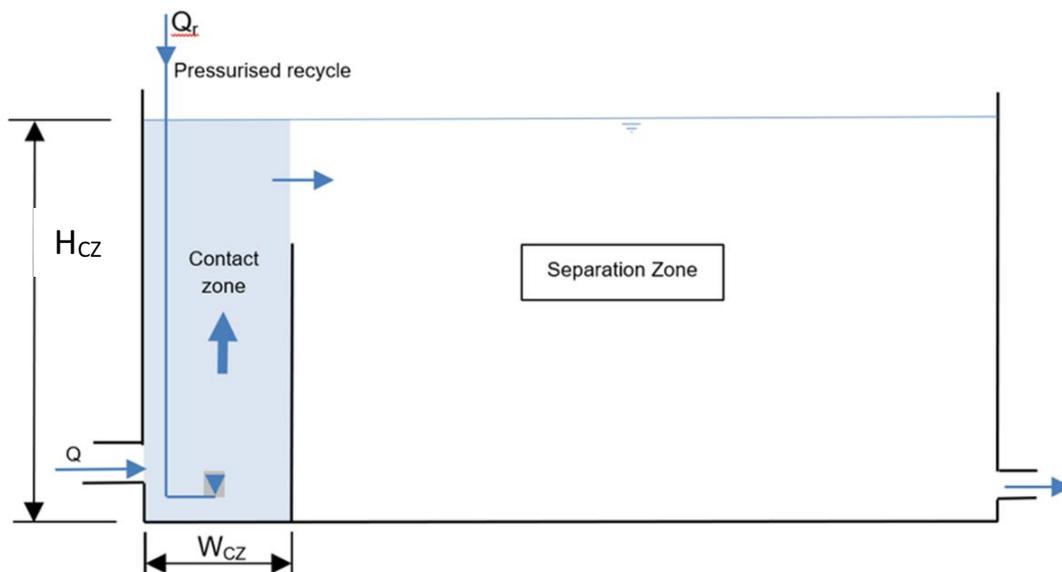
Figure 3-5: DAF schematic showing contact and separation zones

Figure 3.4 shows an idealised version of a DAF contact zone in which plug flow conditions are assumed. The mean residence time in the contact zone is given by:

$$T_{CZ} = \frac{V_{cz}}{Q_i + Q_r} = \frac{V_{cz}}{Q_i(1+r)} \qquad (3.1)$$

In which:
T_{cz} = Mean residence time in the contact zone

V_{cz} = Volume of the contact zone

Q_i = Flow to the DAF facility

Q_r = Recycle flow rate

r = DAF recycle ratio $Q_r : Q_i$

Contact zone performance depends on:

- the reactions (contacts) taking place in the contact zone, and
- the contact zone hydraulics, assuming ideal plug flow conditions.

In the contact zone, the main flow Q_i is vertical, and mixes with recycle flow Q_r as it enters through the recycle nozzles so that some dispersion is expected. Tracer studies by researchers have shown that although some dispersion does occur, plug flow conditions can be approximated if guidelines are adhered to (see Table 3.1). Bringing the main flow Q_i into the bottom of the contact zone (as is common for circular DAF units) aids in achieving near plug flow conditions.

A slight tapering of the walls (although this detracts a bit from producing ideal plug flow conditions) can be useful to reduce coalescing along the walls as bubbles rise through the water column.

3.7 Design guidelines

Table 3.1 below is provided as a guide to designers. Working within these guidelines helps to ensure that near plug flow conditions in the contact zone can be achieved leading to stable particle/bubble agglomerates.

Parameter	Clarification	Thickening
Retention time in contact zone	60 to 120 seconds Average 80 seconds	30 to 120 seconds Average 60 seconds
Hydraulic loading in contact zone	100 to 200m/h	100 to 200m/h
Cross-flow velocity or velocity at the transition between contact zone and separation zone	20 to 100m/h	50 to 200m/h
Depth of contact zone	2 to 3.5m	2 to 4m
Bubble size	40 to 80μm	60 to 120μm
Solids loading without polymer (separation zone)	-	2 to 6 kg/m²/h
Solids loading with polymer (separation zone)	-	6 to 12 kg/m²/h
Note: Cross-flow area is the vertical area through which water passes (more or less horizontally) as it leaves the contact zone		

Table 3-1: Design guidelines for contact and separation zone sizing

3.8 Configuration requirements (summary)

- Particles and bubbles should be in their respective size ranges.

- Enough turbulence is required to provide adequate collision opportunities but avoid high levels of turbulence (often caused by large bubbles) which will break up already formed agglomerates.

- Regions of high shear should be avoided as they lead to unwanted turbulence and coalescing.

- Hydraulics should approximate plug flow.

- Sufficient time is needed to establish stable particle/bubble agglomerates which will float to the surface successfully.

- The contact zone must be confined to a separate compartment ahead of the separation zone.

- Air must be released very close to the point where the recycled water is mixed with the flocculated water to minimize the loss of air bubbles resulting from coalescence.

4 CHEMICAL PRE-TREATMENT

4.1 Application

In the mining industry, flotation requires pre-treatment to modify, stabilise and improve particle / bubble contact to achieve the desired results. In the water industry, ferric chloride, aluminium sulphate and synthetic polymers are typically used for coagulation (in clarification applications), with polymers used as flocculants (typically for WAS thickening). In drinking water applications, where small discreet (sometimes colloidal) particles are present a coagulant is usually required to assist in forming small pin-flocs that can be further flocculated or directly floated.

For WAS thickening, the preferred approach is to design DAF systems without pre-treatment. A correctly designed and operated DAF unit is expected to easily achieve a WAS float concentration of 3.5%. Higher solids concentrations are possible without polymer, but less reliable. Achieving a consistent 3.5% (90th percentile) solids concentration means achieving 3.7 to 3.9% solids concentration as an average.

Polymer should be used for the following reasons:

- when a higher WAS solids concentration is required without increasing the throughput.

- when increased throughput is required without necessarily increasing the float solids.

4.2 Polyelectrolyte dosing and flocculation

Synthetic polyelectrolytes are usually used for WAS. Selection of the right (or best) polyelectrolyte is usually done in conjunction with the polyelectrolyte vendor who usually has multiple products to select from. Unfortunately, the make-up of the products is regarded as the intellectual property of the vendor, so the end user is never certain that the best product for his application has been found. The minimum information that should be required of the vendor are shown in table 4.1.

Minimum information to be provided by polymer supplier:
Type of polymer
Concentration of active ingredient
Concentration of free monomers
Concentration and nature of other impurities
Molecular weight or intrinsic viscosity under specified conditions
Proportion of ionizable groups, and
Amount of insoluble material present.

Table 4-1: Minimum requirements of polymer supplier

With biological sludges, polyelectrolytes used are almost exclusively cationic. They may be added to supplement the natural biological flocculation characteristics of the wastewater.

Bratby, investigating thickening characteristics of activated sludge by dissolved air flotation, found that applying a cationic polyacrylamide with a medium to high charge density (degree of hydrolysis 10 to 30%), molecular weight 10 to 12×10^7 and at a concentration of 2kg/tonne TSS, found that for a given solids loading rate and height of float above the water level, float solids concentrations achieved were consistently higher (by a factor of 1.35) when compared to no polyelectrolyte addition. Furthermore, polyelectrolyte addition reduced the total depth of float solids (d_b) thereby reducing the effective depth of unit required for thickening.

Subnatant solids concentrations from the DAF unit were lower when using polyelectrolytes (mean value 6.7 mg/L compared to 37 mg/L with no polyelectrolyte addition). Bratby suggested that polyelectrolyte strengthened biological flocs were better able to resist break up within the relatively turbulent environment of the flotation unit.

Polyelectrolyte dosing rates for WAS are expected to be in the range of 2 to 4kg/tonne TSS, with the rate being at the lower end of this range for well-designed DAF units.

4.3 Rapid Mixing

Rapid mixing refers to that stage in the flocculation process where polyelectrolyte is added into the WAS stream. The function of rapid mixing should not be considered to be one of merely achieving efficient polyelectrolyte dispersion. The rapid mixing stage is possibly the most important operation as it is here where primary and secondary floc particles are formed, the characteristics of which markedly influence subsequent flocculation kinetics. For polyelectrolytes, where the method of destabilisation is adsorptive in nature, a plug flow facility, imparting a velocity gradient appropriate to the application, is considered to be better than a back-mix device. Techniques that may be used include pipe bends, sudden expansions in the pipe diameter, or an orifice plate in the pipe.

Bratby reported that a series of bends giving an equivalent pipe length of 5 times the diameter will give a sufficient velocity gradient to achieve adequate floc formation using polyelectrolyte on WAS.

4.4 Chemical dosage determination

Determination of correct chemical dosing levels for *clarification* should be carried out through pilot trials. Using a standard jar test for simulating settling in a laboratory is not considered a reliable predictor of DAF performance – settling is a 2-phase process, whereas DAF is a 3-phase process. Laboratory settling tests may be used as initial indicators of chemical dosages but cannot replace proper pilot trials. Commercial bench-scale flotation test devices have been constructed in the past, but do not form a part of any standard procedure.

For *thickening* applications, polymer dosage is best determined on pilot or full-scale units.

Flotation thickening is more vulnerable to overdosing of polymer than sedimentation.

4.5 Pre-treatment for clarification

Coagulation

Coagulation and flocculation are required for dilute suspensions when:

- It is necessary to gather very small particles together as floatable flocs;
- Particles would not have been removed on their own;
- A very high air:solids ratio (a_s) would have been required to remove them.

Rapid mixing of the chemicals into the water is important and should preferably be done with an in-line mixer. Other mixing methods may also be considered on a case-by-case basis. Mixing time is also of importance and should be the subject of laboratory trials.

Flocculation guidance

Table 4.2 below provides guidance on flocculation times and mixing intensities for various waters. These are design guidelines, to be used as indicators of what may be expected in various situations. They must not be used to replace proper trials. Note that at low temperatures, longer flocculation times can be expected.

Water source	Time (min)	Intensity (G) s^{-1}	Gt value
WASTEWATER			
Algal laden waste stabilisation pond water	6 to 12	75	$\geq 1 \times 10^4$
Maturation pond water		130 - 180	$\geq 3 \times 10^4$
SURFACE WATERS			
Algal waters (e.g. Eutrofied impoundments)	12 to 15		$\geq 1 \times 10^4$
General range	4 to 15+	50 - 120	4×10^4 to 8×10^4

Table 4-2: Design guidelines for flocculation and clarification

The type of flocculation is not considered to be important. Baffled hydraulic channels and pipe flocculators are popular because of their simplicity.

4.6 Pre-treatment for thickening

When thickening WAS, flocculation is only required when it is necessary to:

- achieve better than 3.5 to 4% solids in the float.
- achieve good capture (or alternatively low SS in the subnatant water).
- flocculate particles smaller than 20µm.
- reduce the total number of particles.
- improve bubble attachment by changing the nature of the particle surface.
- increase DAF throughput if the unit is at its design capacity.

In WAS applications, polymer addition can typically be expected to:

- increase float solids concentrations by 25 to 35% (normally closer to 25%).
- allow increased solids loading rates of up to 11 to 15kg/m^2/h (the anticipated range for most applications is 6 to 11 kg/m^2/h). (**Note** that the expected initial **solids loading rate** (i.e. without polymer) should always be properly calculated and *NEVER selected arbitrarily*. Proper calculation is shown in Section 5.3).
- improve solids capture to ensure greater than 95% capture (and preferably >98%).

Although the use of polymer may be indispensable in certain instances, it is preferable to operate WAS - DAF systems without polymer. This is to ensure correct design of the DAF system in the first instance, and not rely on polymer to achieve the desired output solids concentration. In some cases polymer addition has produced little or no improvement in the DAF process. It has been speculated that the reason for this was that the original flocculation properties of the sludge were so good that polymer had little further effect.

4.7   Requirement when upgrading a DAF facility

ADDING A POLYMER SYSTEM TO AN EXISTING DAF FACILITY
When adding a polymer system to an existing DAF facility it is important to consider the entire design and not just add polymer in the hope of an incremental increase in performance. Due to potentially increased flows, consideration must be given to the recycle system, contact time in the contact zone, cross flow velocity etc. to make sure that all aspects of the facility still fall within the design parameters outlined in this document. Failure to consider the entire system may lead to system failure in the field.

Table 4-3: Requirement when adding a polymer system to an existing DAF plant

5 BUBBLE PRODUCTION SYSTEM

The bubble production system comprises four main elements, being:

- recycle pump - which pumps recycled water through the saturation system back into the main feed to the DAF unit in the contact zone;

- saturation system - for dissolving air into the recycle water under pressure until the water is nearly saturated with air;

- delivery and distribution system - for delivery of the saturated water to the release point(s);

- injection devices - or nozzles which form the transition between the pressurised (air saturated) system, and atmospheric pressure in the contact zone.
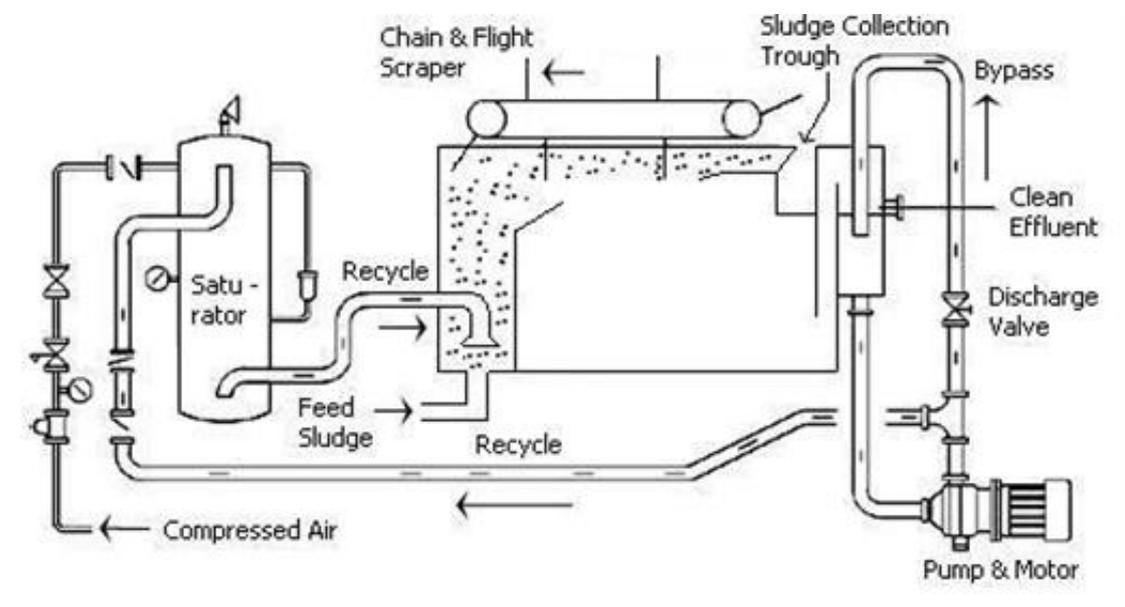
Figure 5-1: Illustration of DAF bubble production system

5.1   Air solubility

The section below sets out a basic approach to air solubility which is sufficient for concept designs. For more detailed information, refer to the Edzwald and Haarhoff (2012) where salinity, altitude etc. are included in the theory.

Air solubility is determined mainly by three factors:

Temperature

Air is more soluble in water at lower water temperatures.

Air pressure

The amount of air that can be dissolved in water is directly proportional to the pressure. i.e. a 3-fold increase in air pressure gives a 3-fold increase in solubility.

Absolute air composition and solubility (Theory based on Henry's Law)

- Air consists for the most part of Nitrogen (78%) and Oxygen (21%). O_2 is more soluble than N_2 and dissolves in the water more rapidly under pressure;

- Under pressure, therefore the N_2 concentration increases, and the O_2 concentration decreases, making saturator air less soluble than atmospheric air (see fig 5.1);

- Air saturation is also altitude and temperature dependant;

- This affects the efficiency of saturators. If stated in terms of atmospheric air, it is impossible to achieve 100% efficiency - in fact no more than 91% would be achievable.

- Saturator efficiency is therefore stated in terms of saturator air.
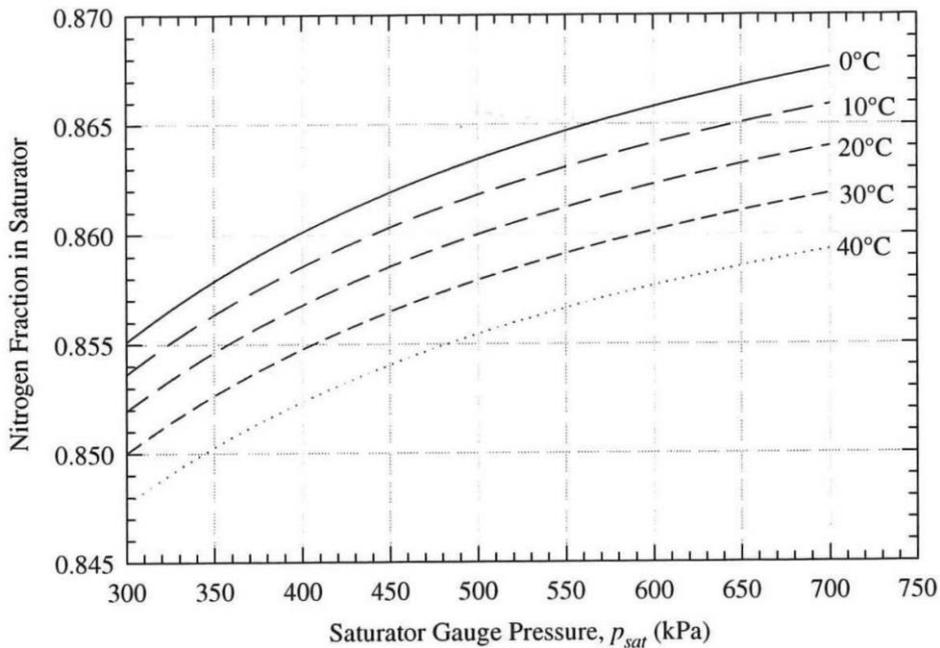
Figure 5-2: Volumetric or molar nitrogen fraction in saturator air as a function of temperature and saturator gauge pressure, at sea level

Calculation of theoretical solubility

Theoretical solubility can simply be expressed as:

$$a_P = S_T \cdot P_{sat} \tag{5.1}$$

In which:

a_p = excess air concentration (mg/L)

P_{sat} = saturator gauge pressure (kPa)

S_T = solubility constant (mg/L/kPa) at temperature T

T = water temperature (degrees centigrade)

         and

S_{20} = 0.242 for atmospheric air

S_{20} = 0.219 for saturator air

For temperatures other than 20ºC, S_T may be estimated from:

$$S_T = S_{20}\left(\frac{293}{273+T}\right) \cdot 10^{-500\left(\frac{1}{293}-\frac{1}{273+T}\right)} \tag{5.2}$$

5.2 Recycle rate

Finding the correct recycle rate is important to ensure that the correct amount of air is recycled to the contact zone for optimum particle/bubble contact.

In *clarification* applications, the air requirement is expressed as a mass concentration per volume, and the recycle ratio is expressed as:

$$r = \frac{C}{S_T \cdot P \cdot \eta_S} \qquad\qquad (5.3)$$

In *thickening* applications, the air requirement is expressed as the dimensionless air:solids ratio a_s and the recycle ratio can be expressed as:

$$r = \frac{a_s \cdot SS_{in}}{S_T \cdot P \cdot \eta_S} \qquad\qquad (5.4)$$

in which (also refer to table 5.1 below):

r	$= $ recycle ratio (dimensionless) $= \dfrac{recycle\ \ flow\ \ rate\ \ Q_r}{raw\ \ water\ \ flow\ \ rate\ \ Q_i}$
C	= required air <u>mass</u> concentration (mg/L) (see figure 5.4)
S_T	= solubility constant (mg/L/kPa)
P	= saturator gauge pressure (kPa)
η_s	= saturator air transfer efficiency in terms of atmospheric air (dimensionless)
a_s	= air to solids ratio → set at ≥ 0.02 for WAS (see table 5.1 for other sludge types)
SS_{in}	= suspended solids in raw water (e.g. SS in WAS stream)

NOTES: THICKENING:

1. *By rearranging equation 5.4 an indication of the minimum a_s can be determined for a particular recycle ratio. This assumes that 100% of the dissolved air precipitates from the water and is translated into bubbles in the required size range, with no coalescing taking place. This is never true, but an indication of the available air is given in Figure 5.3. Guidance on minimum a_s values are provided in Table 5.1. As the solubility constant (S_T) is temperature and altitude dependent it is best to design for a variable recycle ratio.*

$$a_S = \frac{r \cdot S_T \cdot P \cdot \eta_S}{SS_{in}} \qquad \textit{(equation 5.4 rearranged)}$$

2. *The production of sufficient air is the key prerequisite for successful DAF <u>thickening</u> operations.*

NOTES: CLARIFICATION

1. *In the case of clarification, the value of C in equation 5.3 is accepted to be 6–10mg/L with 8–10mg/L being applicable for most applications in Western Australia. (See indicative value of C in table 5.1, and figure 5.4 for values of C at different altitudes and temperatures).*

2. *With the recycle rate determined from equation 5.3, the minimum a_s value for clarification can be determined from equation 5.4.*

Parameter	Clarification	Thickening
r (% of raw water flow)	6 to 20 (average 10-12)	50 to 250 (average 100)
P (kPa)	300 to 750 (usually 350 - 500)	400 to 600
C (mg/L) (based on the influent flow Q – not solids)	7 to 11 (usually 8 to 10 for WA conditions) (see fig 5.4 mass concentration)	N/A
Comment on recycle	Not much gained by using higher recycle ratios	Recycle rate has significant impact on hydraulic loading. Commission at 100% and test down to 70% first.
Comment on C – required air mass concentration for *clarification*	Provide for flexibility. Start at 10 mg/L at commissioning and gradually reduce to find best operating point	N/A
Plant start up	Auxiliary water supply not essential at start up	Requires auxiliary water supply to start up plant

Table 5-1: Design guidelines for recycle, pressure and air mass concentration
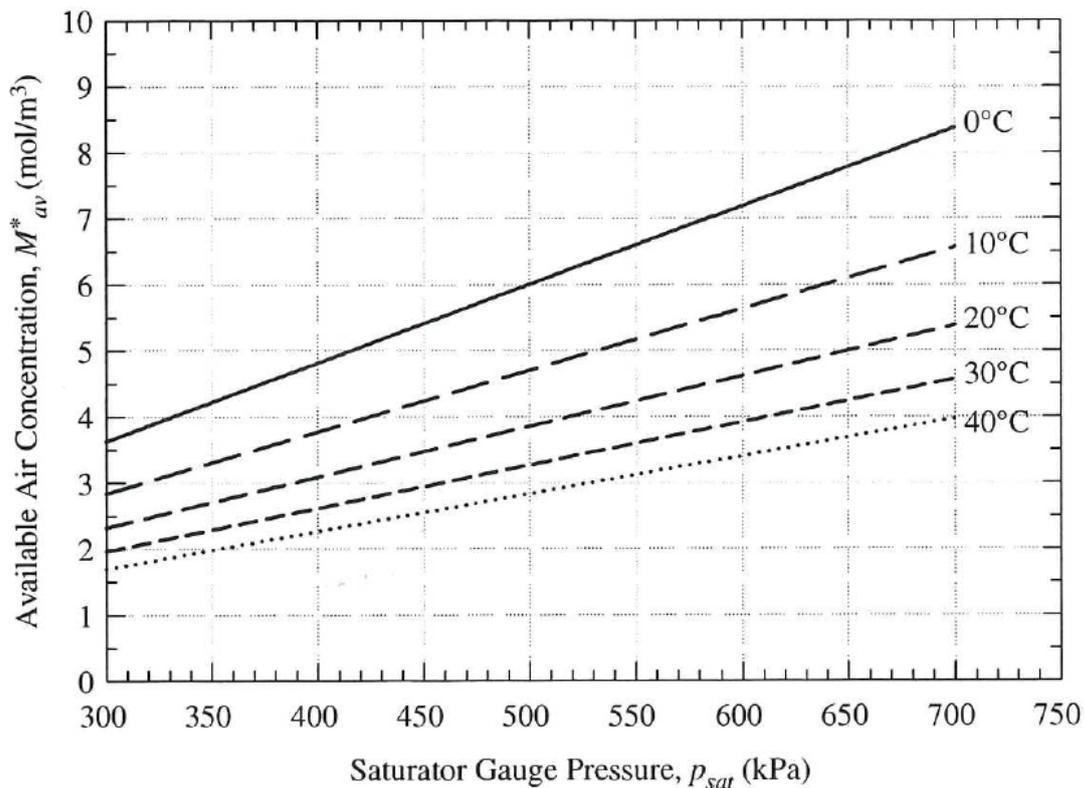
Figure 5-3: Available air concentration from a saturator at complete saturation, as a function of temperature and gauge pressure, at sea level. (Source: Edzwald & Haarhoff, 2012)

Note that the available air concentration indicated is in mol/m^3 and needs to be converted to a mass to determine the air:solids ratio. For more details, see Edzwald & Haarhoff, 2012.
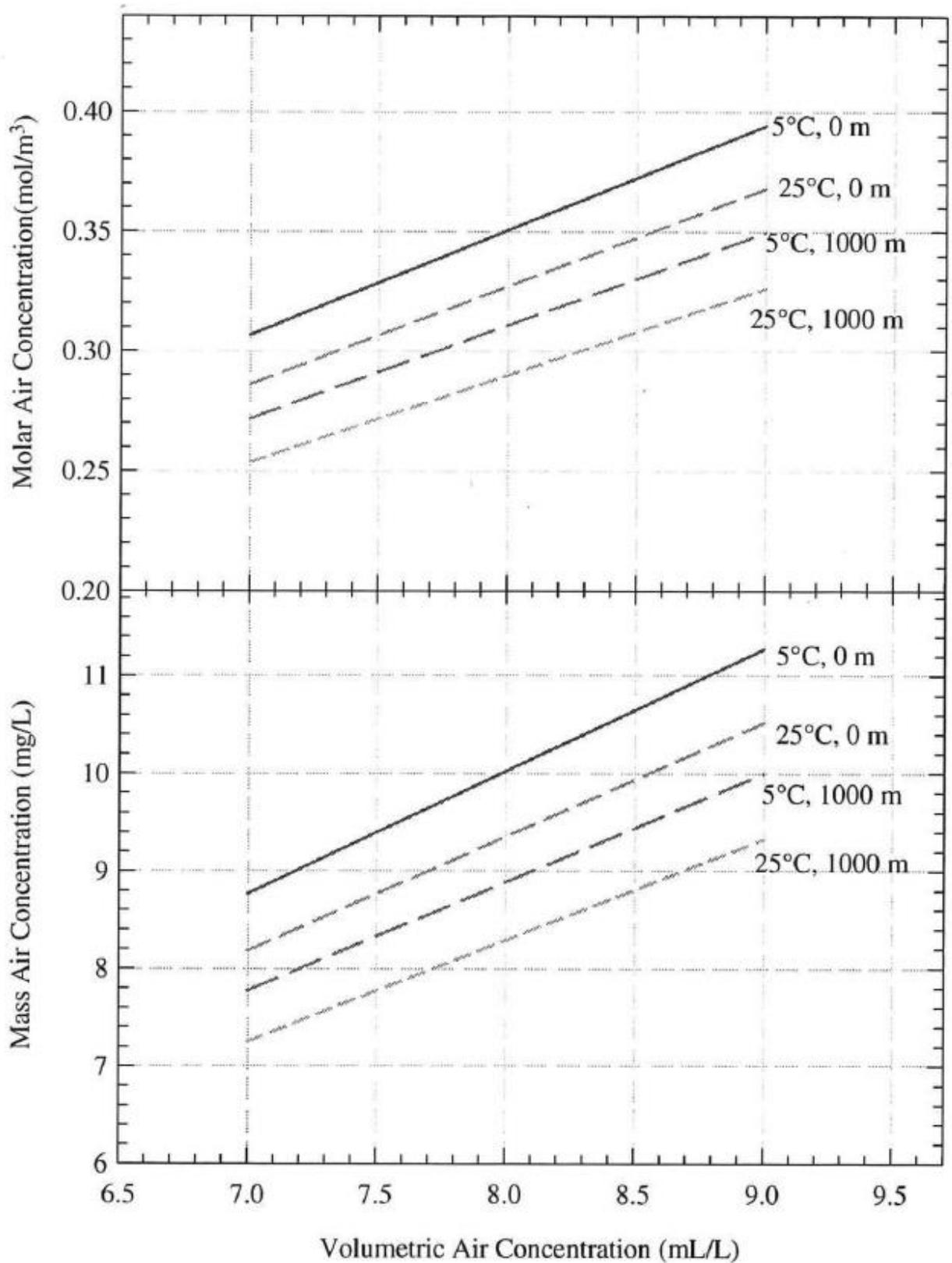
Figure 5-4: Molar (top) and mass (bottom) equivalents of the volumetric air concentration at different temperatures and altitudes (Source: Edzwald & Haarhoff, 2012)

5.3 Saturator types

Refer to Figure 5.5 below.

Unpacked saturator

- This is an all-purpose saturator able to be used in any situation.

- It is the least efficient saturator though, with efficiency being from 50 to 85%.

- It has 3 transfer zones for dissolving air into water:

    1. Incoming drops of water passing through the air cushion above the water.

    2. Entrainment of air as the droplets hit the surface of the water in the saturator. This feature can be considerably enhanced by including a recycle feature on the saturator (see recycling saturator in Figure 5-1: *Illustration of DAF bubble production system*.

    3. Mass transfer at the surface of the water due to the saturator pressure. This feature can be enhanced by creating a convection flow by asymmetrical introduction of the compressed air stream below the water surface.

Packed saturator

- These saturators are partly filled with packing material consisting of plastic packing pieces about 25–50mm in size.

- They are very efficient, with claims of up to 90% efficiency.

- It is assumed that practically all the mass transfer takes place in the packing.

> *NOTE: Packed saturators shall NOT be used for WAS thickening, or in any other application likely to have suspended solids in the recycle stream greater than 5mg/L.*

Internal recycling saturator

- Similar to packed and unpacked saturators discussed, but internal recycling of the water already rich in dissolved air increases the potential to dissolve more air.

- These have potentially high efficiencies with efficiencies of up to 100% claimed.
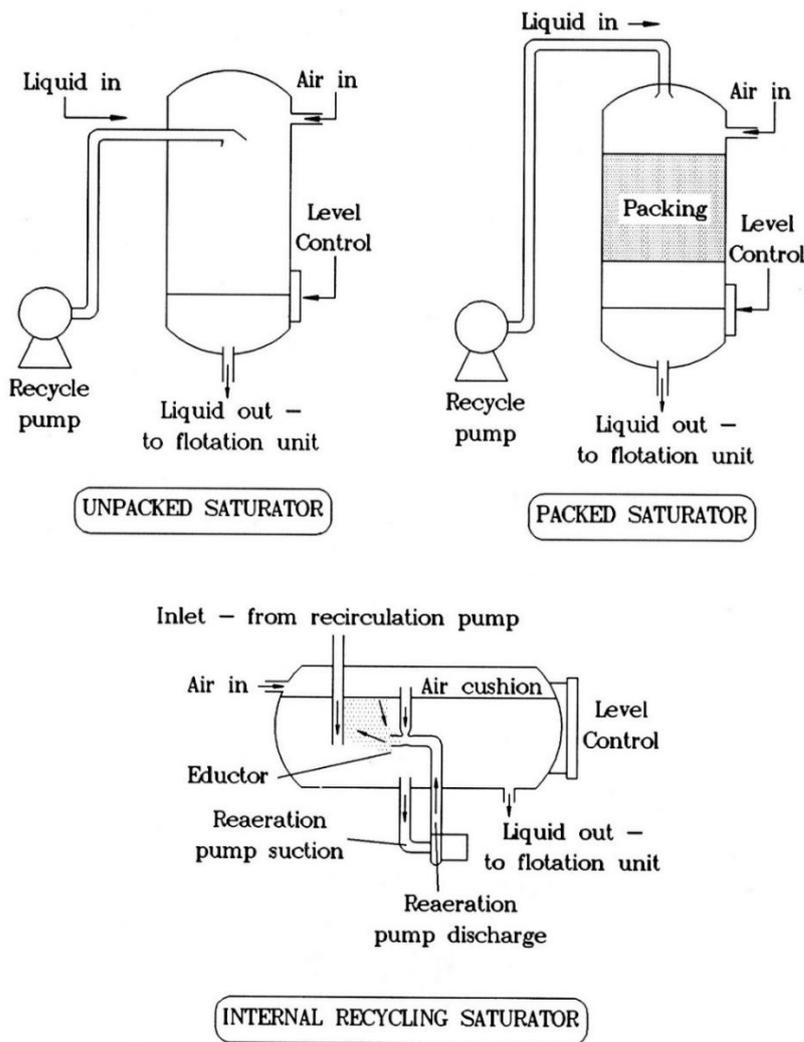
Figure 5-5: Saturator types

5.4 Injection nozzles

Injection nozzles, together with the correct positioning of the nozzles in the DAF system, ***are vitally important to saturator operation***. The nozzles provide back pressure to the saturator to maintain solution of air and control the flow rate into the contact zone.

The nozzles must:

- Release the recycle stream directly into Contact zone ***and*** raw water stream.

- Generate bubbles of uniform size (see section 3.3).

Some practical suggestions for good design and operation:

- Nozzles must be positioned to release pressure into process stream.

- Pressure reduction must be instantaneous (not transitional). Transitional pressure reduction leads to bubbles of varying sizes being formed with the negative process consequences discussed in Section 3.3.

- Bubble formation can be improved if released through a number of small holes.

Nozzle types

Various types are available (including various patents):

- Most are fixed nozzles that cannot be adjusted.

- Fixed nozzles have the disadvantage that it is necessary to drain the tank to change them for nozzles of a different size if required.

- Externally adjustable nozzles are better from an operations perspective, but difficult to apply on large tanks where several nozzles are required. Adjusting an assembly of nozzles and achieving equal adjustment on each is almost impossible.

The more common nozzle types in use are diaphragm valves and needle valves. The main advantage of these (and probably the main reason for selecting them) is that they can be adjusted from outside the tank.

- Diaphragm valves are not very efficient due to having a transition zone that leads to bubbles of varying size.

- Needle valves with a narrow seat (<3mm) are a better alternative, offering a rapid transition and fairly even bubble sizes.

To pass turbulent flow, a nozzle must obey the fundamental hydraulic relationship[1]:

$$\frac{r \cdot Q}{n} = C_d \cdot A_n \cdot \sqrt{2 \cdot g \cdot h_n}$$

In which:

A_n = area of nozzle opening(s) (m^2)

C_d = nozzle discharge coefficient

           = 0.61 to 0.64 (typically)

h_n = head loss across injection nozzle (m)

n = number of nozzles

$r.Q$ = recycle flow rate (m^3/s)

---

[1] This relationship can be derived from the well-known equation ($h = k \dfrac{v^2}{2gd}$) for transition losses in pipe systems as follows:

$$h = k \frac{v^2}{2gd}$$

$$h = k \frac{Q^2}{2gd \cdot A^2} \qquad\qquad \because v = \frac{Q}{A}$$

$$\Rightarrow Q^2 = \frac{d}{k} \cdot A^2 \cdot 2gh \qquad set \sqrt{\frac{d}{k}} = C_d$$

$$\Rightarrow Q = C_d \cdot A\sqrt{2gh}$$

6 SEPARATION ZONE

6.1 Particle buoyancy and air requirements

The designer must first consider how much air is required to counteract the gravitational force on the solids in the water **and** float them to the surface. The air requirements are therefore expressed as the dimensionless ratio of air:solids (a_s).

Theoretically it should be easy with the mass of solids (or the Specific Gravity (SG)) known. The mass of air required could be calculated (assuming 100% efficiency). Unfortunately, efficiencies vary significantly, the following being an indication:

- Raw wastewater   20 to 50%
- Activated sludge   2.5 to 25%

These ranges in efficiency mean that actual calculation of the air:solids ratio (as in equation 5.4) can only be used as a guide to the minimum air:solids ratio required. Thus, recommended minimum values have been provided in Table 6.1 below. It is recommended that design be based on these minimum values (for efficiency reasons), and provision be made in the design to increase to above these values in operation. It should be noted that the air:solids ratio influences the amount of air adsorbed to the particles, and thereby directly influences the rise rate of bubble-agglomerates.

Studies have shown that, as long as a certain minimum threshold air:solids concentration is reached, the role of the air:solids ratio as does not appear to be that important. This indicates that air is a necessary condition up to a point beyond which additional air has little if any further effect.

Product to be floated in the DAF unit	Recommended minimum air:solids ratio a_s	Application
Waste activated sludge (no polymer)	> 0.02 (range 0.02 – 0.04)	Thickening
Waste activated sludge (with polymer)	> 0.02 (range 0.02 – 0.04)	Thickening
Raw wastewater	> 0.06 (range 0.06 – 0.12)	Clarification
Raw wastewater using metal coagulants	> 0.06 (range 0.06 – 0.12)	Clarification
WSP algae using Alum or Ferric chloride	> 0.03 (range 0.03 – 0.08)	Clarification

Table 6-1: Design guidelines for limiting (minimum) values of a_s

Notes:
- *Higher a_s values are required for more dilute suspensions.*
- *The a_s ratio is more critical in thickening than clarification operations. This is because for clarification (already low in suspended solids), design is mainly based on hydraulic loading whilst design for thickening is mainly based solids loading.*
- *For clarification a_s is really only used for determining the limiting downflow velocity (v_L) whereas it is required for sizing of much of a thickening DAF.*
- *Values of a_s are based on air precipitated, not on the actual quantity attached to particles.*

6.2   Hydraulic loading (down-flow velocity)

The hydraulic loading (limiting down-flow velocity) determines the area of the separation zone for ***both thickening and clarification operations***. The actual down-flow velocity must be lower than this value to ensure that particle/air agglomerates that have passed from the contact zone are not drawn down. If this velocity is too high, the subnatant (underflow) quality will be compromised. The relationship between v_L and a_S is given by the following equation:

$$v_L = K_1 \cdot a_s^{K_2} - K_3 \qquad\qquad (6.1)$$

In which:

v_L = limiting hydraulic loading (m/h) i.e.: $v_L \leq \dfrac{Q_i(1+r)}{A_{sz}}$ (m³/m²/h)

a_S = air to solids ratio   (kg/kg)

K_1 = empirically determined constant for a particular water

K_2 = empirically determined constant for a particular water

K_3 = natural settling velocity of the particles, empirically determined

A_{sz} = minimum area of the separation zone

Notes:

1. $K_3 = 0$ for suspended particles that do not have a natural tendency to settle e.g. eutrophic impoundment water, or waste stabilisation pond effluent.

2. For clarification v_L can vary quite widely with the general range being 5 to 15m/h

3. For WAS thickening v_L is normally in the order of 6.2m/h

The values of K_1, K_2 and K_3 have been empirically determined for various types of water and are given in Table 6.2.

Type of suspension	K₁	K₂	K₃ (m/h)
Clarification			
Raw municipal wastewater	700	1.78	1.0
Raw municipal wastewater (with Alum or ferric chloride)	700	1.78	1.0
Waste stabilisation pond effluent (with Alum or ferric chloride)	3690	1.92	0.0
Eutrophic impoundments	68	0.91	0.0
Thickening			
Waste activated sludge (WAS)	231	0.87	1.5
Waste activated sludge (WAS) (with polymer)	231	0.87	1.5

Table 6-2: Design guidelines for values of K₁, K₂ and K₃ (Also see Table 6.4)

	Clarification	Thickening
Solids loading without polymer	-	2 to 6 kg/m²/h
Solids loading with polymer	-	6 to 12 kg/m²/h

Table 6-3: Guidelines for Solids Loading Rate (SLR) of the separation zone (this is best calculated as set out in this section

6.3 Design equations

The following empirical (regression) design equations have been developed by Bratby & Marais for the determination of the side wall depth of a DAF unit. The image represents the side wall of a DAF unit showing the parameters listed below.

$$d_w = 0.025 C_F + 0.19$$

$$C_F = K_4 \cdot d_w^{K_5} \cdot SLR_{sz}^{-K_6} \qquad 6.2$$

$$d_b + d_w = d_w \left(1 + K_8 \cdot a_s^{-K_7}\right)$$

$$\Rightarrow d_b = d_w \cdot K_8 \cdot a_s^{-K_7}$$
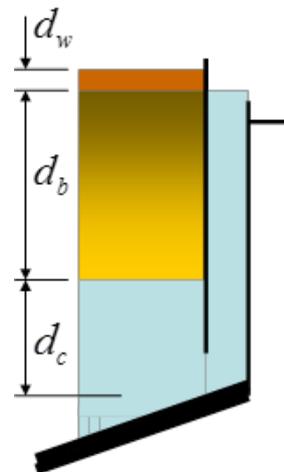
In which:

d_w	= depth of float layer above the water	(m)
C_F	= float layer concentration (designer selected)	(mg/L)
SLR_{sz}	= solids loading rate in separation zone	(kg/m²/h)
d_b	= depth of float layer below water level	(m)
$K_4 - K_8$	= constants for different types of sludge (see table 5.4)	
d_c	= clarification depth (min. 0.5m clear water)	(m)

The constants $K_4 - K_8$ have been determined from laboratory-controlled pilot scale trials and tested in the field on a large number of DAF units. Table 6.4 gives values for these constants for WAS thickening and some clarification operations. The information for WAS operations is the most reliable and has been tested on a number of Water Corporation and other sites.

Notes:

- The depth of the float layer d_w should be at least 150 mm above the water level to ensure reasonable stability of the float layer during sludge scraping.

- The depth of the float layer below the water surface d_b is required to ensure sufficient transition between thickening sludge and the clear water layer below. The curtain wall, below which clear (subnatant) water passes, must be at least down to $d_w + d_b$ in depth, and preferably with a 0.5m safety margin added (see next point).

- A depth of at least 0.5m of clear water must be allowed at the bottom of the tank as a "clear water" zone to ensure minimum suspended solids in the subnatant.

- Storage must be provided in the bottom of the tank for sludge that may settle and accumulate prior to withdrawal. In circular tanks this is usually accommodated in the conical bottom. In rectangular tanks, unless there is a sloping floor, an extra depth must be provided, and a minimum of 200mm is recommended. A series of inverted pyramid shaped hoppers is a common practice.

- A higher air:solids ratio a_s will result in a more compact sludge layer (C_F), and increased rate of compaction (but only up to a certain point – each sludge has its own optimum). The effect often tapers off at a_s ratios > 0.026 for WAS.

- The air:solids ratio a_s has a significant effect on the ratio d_b/d_w

- The depth of float layer has big impact on C_F

Constant	Activated sludge	Activated sludge with polymer	Raw sewage with Alum or Ferric chloride	WSP with Alum/ferric chloride
K_4	6.48	11.22	6.87	9.99
K_5	0.2	0.22	0.08	0.13
K_6	0.5	0.4	0.50	0.47
K_7	0.45	0.45	1.52	0.8
K_8	0.76	0.5	0.0385	0.43

Table 6-4: Constants for regression equations 6.2

6.4 Configuration

Some comparative comments on circular and rectangular DAF units are given below.

CIRCULAR	RECTANGULAR
Decreasing velocity towards the outer edge	Easily housed inside buildings
Simpler rake arm mechanism	Multiple units cheaper due to shared walls
Cheaper – more area per unit wall length	Hopper bottom (if so designed) eliminates bottom scraper
Lower outlet weir loading	
Bottom scrapers are cheap	Prefabricated units can be transported
Top mounted drive eliminates wet bearing	Easier introduction of water

Table 6-5: Comparison between circular and rectangular DAF

Some practical issues

- Circular units are often preferred to rectangular for WAS thickening.

- Broad short tanks are better than long narrow ones for rectangular DAFs.

- Use a L/W ratio of 2.5 for clarification (up to 3.5 for thickening is still acceptable).

- Typical side wall depths can vary for clarification.

    o Algal waters (clarification) 3.5m

    o Clarification (other)   1.0 to 3.2m

- The draw off system can have a big impact (see Figure 6.1 below)

    o Pipe array at bottom will give a nice steady flow (rarely used though)

    o Launder can cause density currents within the tank

- A roof over a DAF unit eliminates disruption by rain.

- Beware of windy areas where wind could disrupt the float layer.
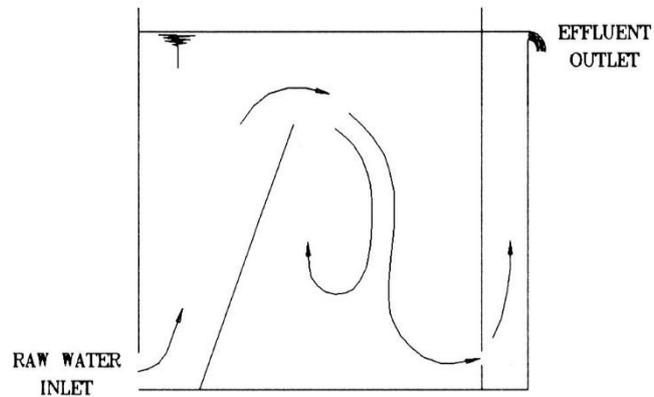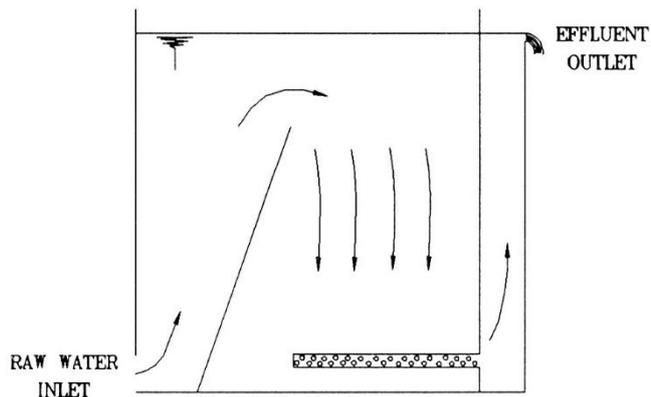
Figure 6-1: Flow patterns of two sub-natant collection systems for rectangular DAF units

6.5   Graphical understanding of DAF operations

Figures 6.2, 6.3 and 6.4 below are provided for visual understanding of DAF system operation.

WAS DAF without polymer

Figures 6.2 and 6.3:

- Sludge type: Waste Activated Sludge with *no polymer*
- Feed SS: 3,600mg/L
- Flow rate: 10m³/h
- Air:solids ratio   0.02
- Recycle rate required: 0.78 (calculated)
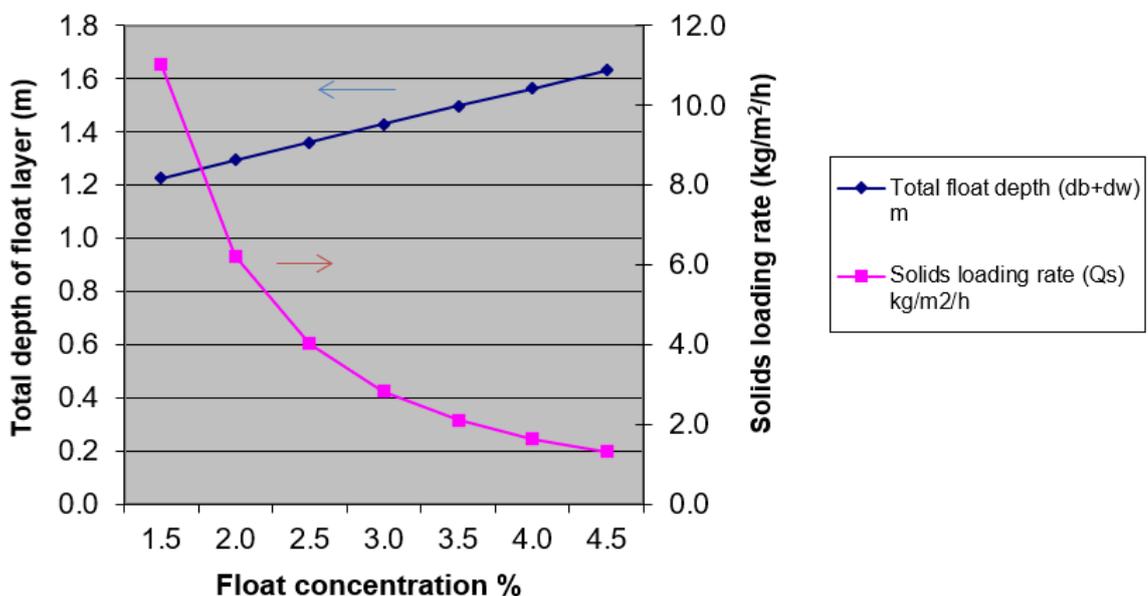
Figure 6-2: Float concentration vs total float depth and solids loading rate

From *Figure 6-3* we can learn the following:

1. Based on a requirement to achieve 3.5% float solids, the SLR is 2.05kg/m2/h. From this it can be shown that a circular DAF of 4.8m in diameter is required.

2. If the requirement is to achieve 3.0% float solids, then a solids loading rate of 2.75kg/m2/h can be applied and a circular DAF of 4.2m diameter is required.

3. The limiting downflow rate is constant at 6.2m/h

4. As the SLR increases, so does the actual downflow rate.

5. Once the actual downflow rate exceeds the limiting downflow rate the DAF will fail due to high levels of SS being dragged down with the subnatant.

6. To achieve a float solids concentration of 3.5% and better, the solids loading rate needs to be no more than 2.05kg/m²/h
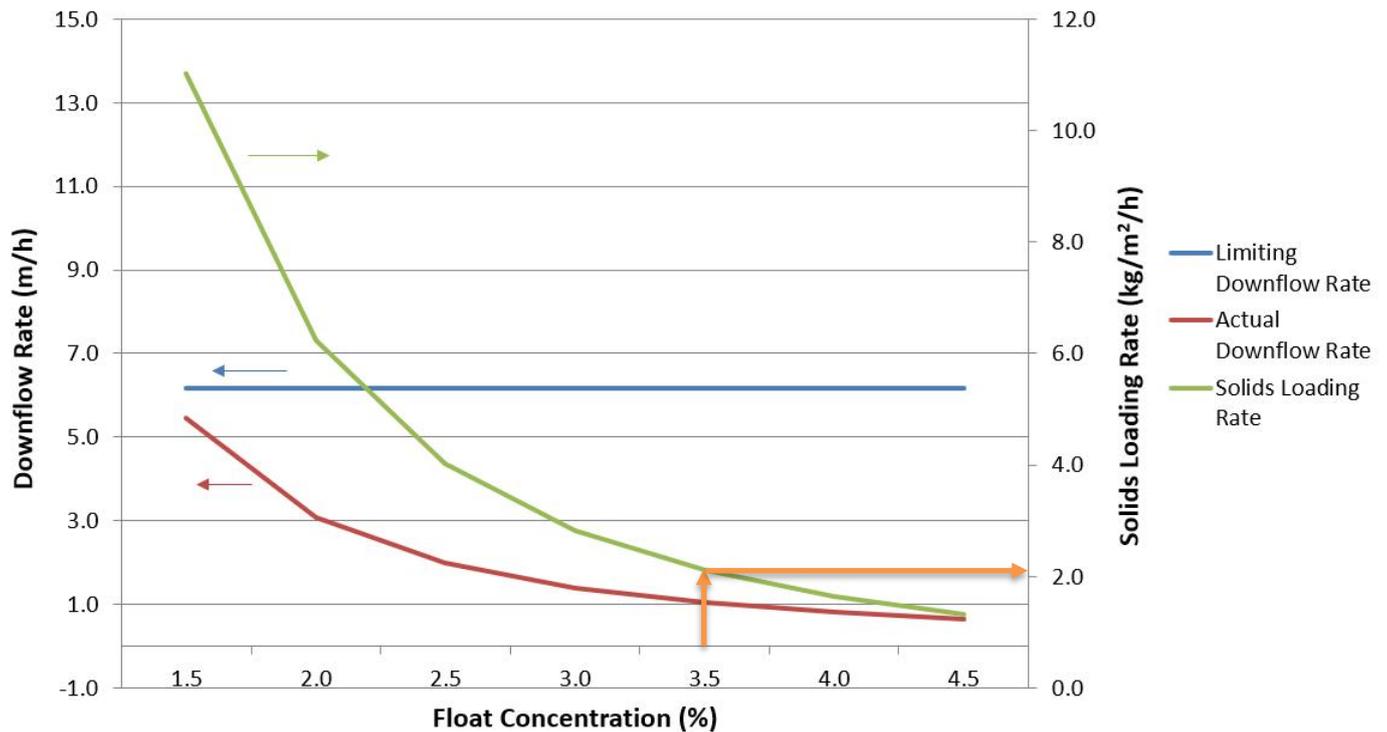
Figure 6-3: Downflow rate and Solids Loading Rate (SLR) vs Float Concentration

WAS DAF with polymer

Figure 6.4 is an illustration of a DAF facility with the following inputs:

- Sludge type: Waste Activated Sludge *with polymer*
- Feed SS: 4,859mg/L
- Flow rate: 231m³/h
- Air:solids ratio   0.02
- Recycle rate required: 1.11 (calculated)

From figure 6.4 note the following:

1. The limiting downflow rate is 6.2m/h

2. To achieve 3.5% float solids, the SLR needs to be 9.7kg/m2/h leading to a DAF of 7.0m in diameter.

3. Where the actual and limiting downflow rate curves cross, it is possible to see that the absolute limiting SLR is 13.9kg/m2/h (giving a DAF unit of 5.9m in diameter and a float concentration of 3.0%).
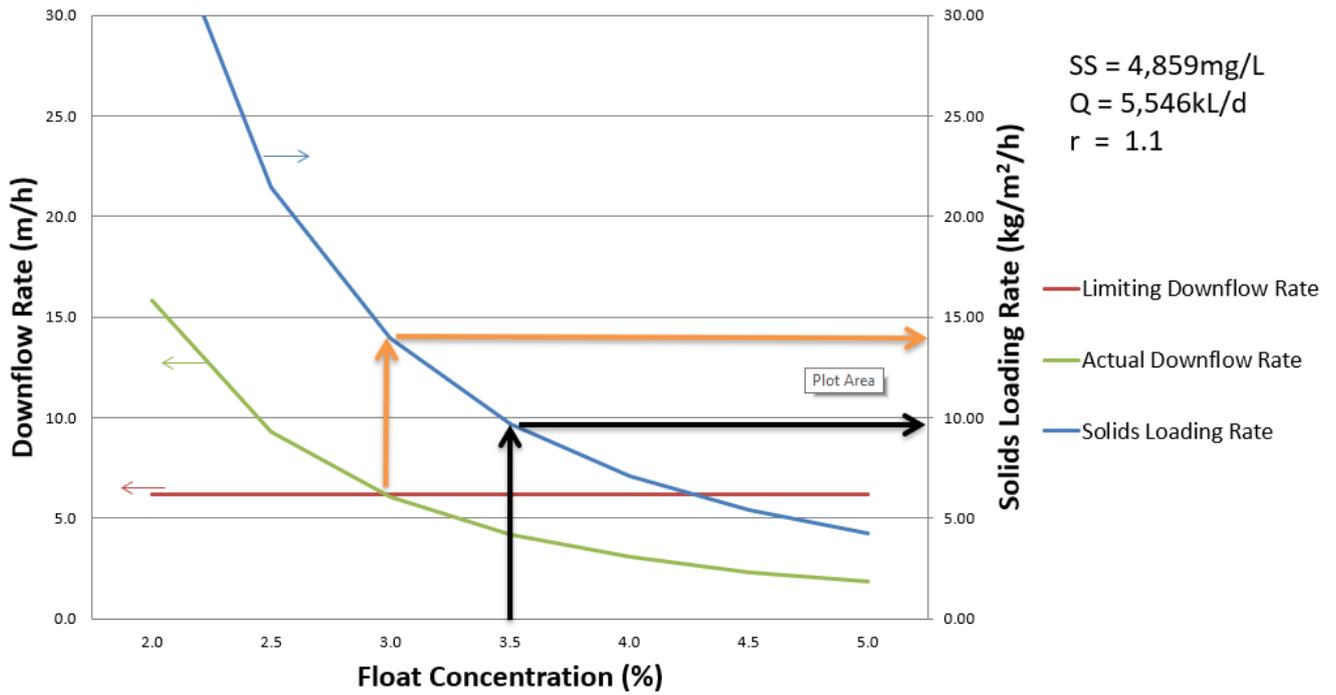
Figure 6-4: With Polymer Downflow rate & Solids Concentration vs Float Concentration

7 FLOTATION LAYER REMOVAL

7.1   Float layer stability

Two conditions of stability are of interest

- First, the layer must remain stable during normal operation i.e. sludge must not break away from the bottom of the compacted layer and sink before being scraped off. Some types of sludge (particularly those encountered in water treatment clarification operations) tend to be stable for shorter periods of time and sink within 30 minutes.

- Second, if the plant is to operate intermittently (as is often the case in WAS thickening), then the layer must remain stable for an extended period of time. Trials have shown that thickened WAS can be stable for up to 4 days, but this varies from plant to plant. In plants in Mandurah (Gordon Rd, Hall's Head, Caddadup) and Kwinana, the sludge layer thickened from 3.8% to nearly 4.5% over night whilst the system was turned off with no ill effect on the subnatant quality. If this occurs, there may be benefits in operating the scraper system intermittently to achieve slightly higher solids concentrations, as long as the subnatant quality remains unaffected.

7.2   Float layer removal

Some comments on the float removal system:

- In general, this is done by way of a scraper arm that moves the thickened sludge to a trough from where it is removed from the tank.

     o   Scrapers are more common in thickening operations.

     o   Scraper blades should extend into the float layer, but not through it, in such a manner that it scrapes off the upper part of the float layer (see fig 6.1).

     o   The depth of the scraper into the float layer should be adjustable, so that optimum performance can be achieved.

- In some instances, the float layer is floated off in an intermittent operation.

     o   This is more common with clarification operations and with DAFF.

     o   It is done by either raising the water level or lowering of a weir which allows the float layer to drain off.

- In DAFF operations it is usually done by raising the water level because the filters are backwashed at the same time, which means that a larger volume of water is drained on each cycle. DAFF systems usually lose about 1.2 to 2% of water with each flush.

- Variable speed scrapers will give the flexibility to find an optimum speed.

- Intermittent scraping often deteriorates the subnatant quality but produces a thicker sludge.

- In rectangular tanks the direction of scraping does have an impact. Surveys have shown that scraping AWAY from the inlet produces better results.

- Beach plates in front of sludge collection hoppers must have a horizontal approach section to prevent sludge from being pushed under the beach plate. See Figure 7.1

- Drainage of the sludge away from the tank once it is collected in the hopper is critical, and the following points should be noted:

     o   Pipes should be steeply graded to ensure sludge does not "hang up".

     o   Pipes should be kept short with the release point preferably providing a free fall into a collection tank or sump for pumping away.

o   Provision for rodding (cleaning) of these pipes is to be made possible.
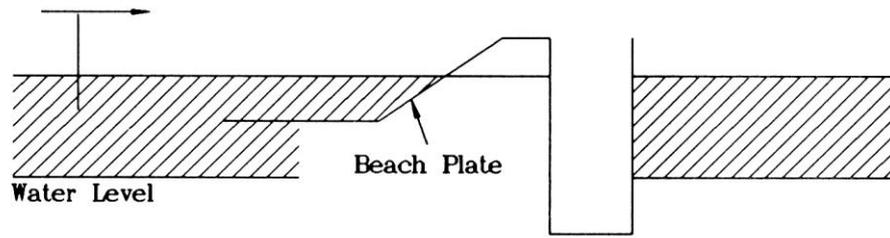
Figure 7-1: Cross section through a beach plate to show horizontal approach

DAF type	Scraper tip speed
Circular DAF	50 to 200m/h
Rectangular DAF	20 to 100m/h
Recommended for Algal water	60m/h

Table 7-1: Guidelines for scraper speed

8 COMBINED FLOTATION / FILTRATION (DAFF)

8.1 General

DAFF (Dissolved Air Flotation and Filtration) systems consist of a tank which has a filtration zone at the bottom in addition to the standard DAF zone at the top. The majority of solids are removed by Separation, and the separation zone acts as a polishing phase for removing the remainder of the solids. For practical reasons they are rectangular in shape.

Some brief comments are worth including.

- DAFF is usually used on water treatment plants, and not for WAS thickening.

- Advantages are:

    o Cost savings brought about by a single structure

    o DAFF is often operated without a scraper system. i.e. the float is flushed off:

        ▪ If DAFF is used for thickening of WAS, a scraper system will also be required.

        ▪ The stability of the float layer must be monitored.

    o DAFF allows longer runs on the filter beds:

        ▪ Up to 80% of the solids are floated whilst only 20% would pass through the filter.

        ▪ This allows an extension of the backwash cycles from 4 to 48 hours.

    o The head loss across the filter is smaller for longer.

    o Less water is lost through backwash.

- Design issues to be aware of are:

    o Drawing minute air bubbles down into the filter, causing blockages after coalescing.

        ▪ This is known as air binding.

        ▪ Binding rapidly increases head losses across the filter.

    o Binding is found not to occur if hydraulic loading is kept below 10m/h in eutrophic waters – i.e. watch the filter rate, and compare with the limiting downflow velocity v_L of the separation system – always use the lower value in design.

    o Binding can be a significant problem for WAS DAFF units as the recycle rate is high, and thus a large volume of air is released as part of the process. Increasing the depth of the tank in addition to checking the hydraulic loading against the filtration rate can help to prevent this problem.

    o Beware of bubbles that are too small which can promote binding.

    o Polymer increases head loss on the filter. In clarification applications (which are more common), a coagulant such as ferric chloride is normally used.

    o With polymer, flocculation is more rapid, and more frequent flushing is required.

    o Filter sand should be finer than for normal 'filtration only' plants.

8.2   CoCoDAFF

The CoCoDAFF (counter-current dissolved air flotation filtration) is an innovative combined flotation–filtration design introduced in the 1990s in which air and water flow counter-current as against co-current in the conventional dissolved air flotation process. Air is introduced with recycle water across the total tank sectional area below the flotation zone and therefore only the filter surface loading rate should include the recycle flow. The aim is to increase the particle–bubble interaction times and have the flocculated water pass through a greater volume of bubbles. CoCoDAFF introduces the recycle flow above the filter media through special high-rate nozzles that are designed to widely disperse the bubbles and thereby reduce the number of nozzles needed. Figure 8.1 shows the typical arrangement of a CoCoDAFF tank.

The primary advantages of the CoCoDAFF are:

* improved particle–bubble interactions to increase the flotation efficiency.

* enhanced support of the floc blanket through continuous, evenly distributed introduction of the bubble blanket.

* reduced operational costs, achieved by turning off the DAFF process during normal raw water conditions and allowing the plant to operate in a direct filtration mode.

The CoCoDAFF has surface loading rates of 10 to15 m/h with recycle ratios of 10%. Loading rates on the DAF zone are effectively limited by the filter loading rates, which tend to be less than those feasible by DAF alone, and then the DAF recycle is added to the filter loading rate while it is not normally considered part of the DAF loading rate.
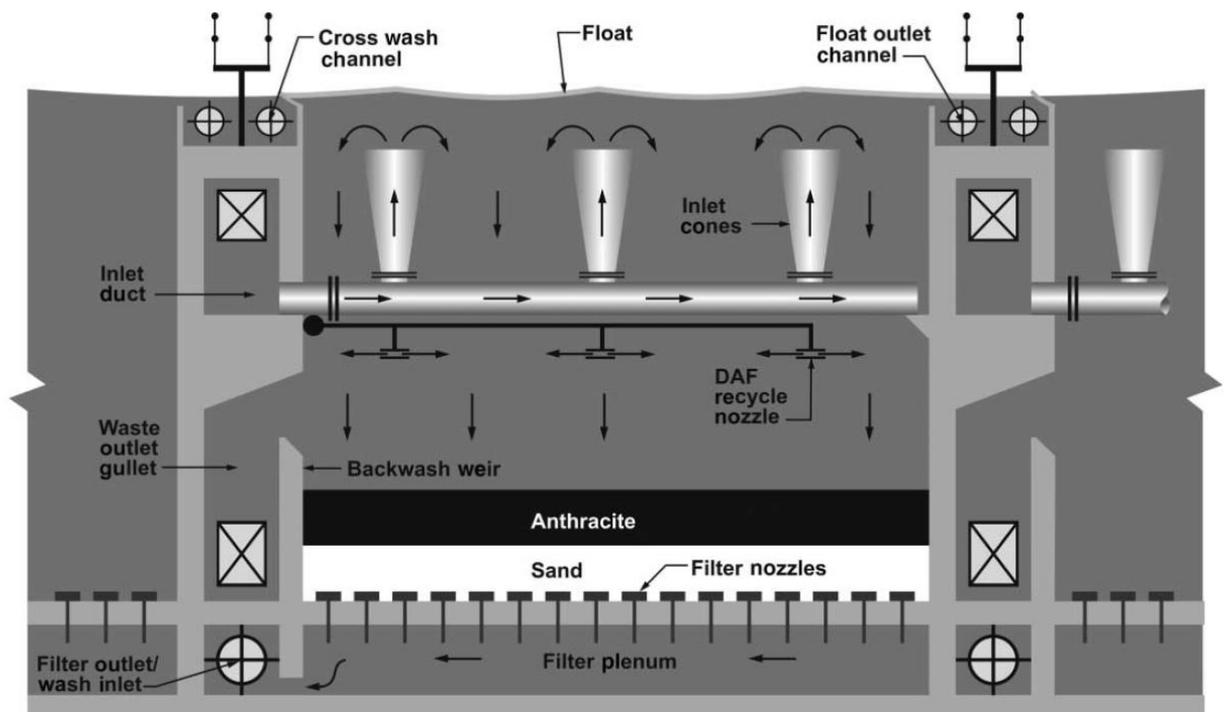
Figure 8-1: Schematic cross section of a CoCo DAFF

9 DAF PERFORMANCE MONITORING

(Contribution by Bradley Shand)

Performance and monitoring

DAF performance monitoring programs shall be designed to ensure an understanding of and achievement the following four classes of data / information:

1. How well the process is currently meeting expectations externally (lagging indicator)
2. How the process in performing internally (lagging indicator)
3. Potential future risks with regards to being able to meet expectations in the future. (Leading)
4. Supporting Data

To achieve this outcome, design data, SCADA data and laboratory analysis data needs to be assessed.

Design Data

The parameters specified below are those required to assess the performance of the process. It is not an exhaustive list, and additional parameters may be required for the actual design standards.

Item	Measure	Unit	Purpose
Contact zone	Plan area	m²	Compliance with Table 3.1
	Height	m	Ensures min contact time is achieved
Flocculation	Time	-	Gt value for flocculation. Table 4.1
Recycle pump(s)	Flow	L/s	Check that range of flows required can be achieved. Table 5.1
Saturator	Pressure	kPa	Confirm pressure and volume match design and fall within the guidelines. Table 5.1
	Volume	kL	
Compressor and air:solids ratio	Pressure	kPa	Confirm that sufficient air can be delivered to meet demand. See Table 6.1
	Capacity		
Separation Zone	Area	m²	Confirmation that area is large enough not to exceed design SLR and achieve TWAS target concentration. See Table 3.1
	Depth	m	Hydraulic loading rate.
			Calculation in line with Chapter 6
Scraper speed	Velocity	m/h	See Table 7.1

SCADA Data

To support operations in the "instant", SCADA data is essential. SCADA data is required for two purposes:

1. To run the plant in the instant.
2. To collect data required for long term performance diagnostics and reporting in the analytical platforms.

The following items are required for monitoring process performance. These are in addition to the standard feedback that individual assets generate (such as state, status and fault codes).

Location	Parameter	Units	Purpose	Required for Instant	Required for analysis
Feed Flow	Flow Rate	L/s	To determine the flow going into the unit	Yes	
	Flow Totaliser	m³	Total flow through meter		Yes
Scraper Motor	Torque	Nm	Measures the resistance of the scraper to movement, solids indicator	Yes	Yes
	Power	kW	Measure the power draw of the motor, supports energy management and motor performance data		Yes
Recycle Flow	Flow Rate	L/s	Determine the flow going into the unit	Yes	Yes
	Flow Totaliser	m³	Total flow through meter		Yes
Recycle Pump	Speed	%, Hz, RPM	Speed of the recirculation pump. Used in pump performance calculations		Yes
	Power	kW	Power draw of the pump motor is used to assess pump performance		Yes
Recycle Pump Upstream	Pressure	kPa	Optional. Required if supply to pump is complex with many curves. Used to assess pump performance		Yes
Saturator Vessel	Pressure	kPa	Pressure at which the air and water contact. Used in multiple functions	Yes	Yes
	Temperature	ºC	Temperature of water in the contact vessel. Required for A:S ratio data		Yes
Compressed Air Supply	Flow Rate	L/s	Flow rate of air into the contact vessel Used for A:S data. Only required on larger units.		Yes
Subnatant Flow	Flow Rate	L/s	Flow Volume is required to assess overall capture rates		Yes
	Flow Totaliser	m³	Flow Volume is required to assess overall capture rates		Yes

Sampling Program

The sampling program shall be designed to provide an understanding as to the internal operating conditions of the DAF unit. Sampling represents performance at a single point in time, and due to the large effort requirements, care needs to be taken with regards to the complexity and frequency of sampling. Ideally samples are all taken at or about the same time each cycle, to ensure a single complete picture of performance.

The following Sample points and parameters shall be designed for a single DAF unit. If multiple units are running in parallel the feed and polymer sample points may be merged, but the separate product sample points shall be monitored individually.

Flow	Analyte	Units (typical)	Frequency (minimum)	Purpose
Feed	Suspended Solids	mg/L	Weekly	To determine the mass load of solids into the unit
Thickened Sludge	Total Solids	%TS	Weekly	To determine the quality of the product
Subnatant	Suspended Solids	mg/L	Weekly	To determine the quantity of solids not captured
Polymer Solution (If applicable)	Total Solids	%TS	Weekly	To determine the mass load rate of polymer being applied

Performance Indicators

The dominant performance indicators are divided into the four classes listed above.

Guidance values are given in some cases, others on a project by project basis

Class	Parameter	Units	Purpose	Guidance Values
1	TWAS Solids Concentration	% TS	Total Solids of Thickened sludge flow	>3.5% for WAS
1	Subnatant Suspended Solids Concentration	mg/L	Solids not captured	<20mg/L
1	Solids Capture Rate	%	Percentage of solids captured in process	>95%
2	Polymer Consumption Rate	kgAM/tDS	Specific Polymer usage rate	<2.5kg/tDS
2	Air To Solids Ratio	mg/mg	Uplift force on solids	Table 6.1
2	Solids Loading Rate	kg/m^2/h	Solids Loading Rate on area	As per design
2	Residence Time	min	Contact time of air and solids	As per design
3	Pump Performance	% Eff, kWh/kL	Pump Machine Performance	

Class	Parameter	Units	Purpose	Guidance Values
3	Scraper Motor Torque	Nm	Calibrate torque to TWAS concentration data	Vendor supplied
4	Polymer Concentration	%TS	Concentration of polymer solution being applied to DAF	From jar tests
4	Feed Solids Concentration	%TS	Concentration of Solids being fed to DAF	Depends on source
4	Daily Volume Feed	m^3	Total Volume feed to DAF	Based on design
4	Daily Volume Subnatant	m^3	Total volume of Subnatant from DAF	Reduced by efficient operation
4	Daily Volume TWAS	m^3	Total volume of TWAS from DAF	Based on design and desired SRT
4	Daily Solids Mass Feed	kg	Total Feed Solids Mass	Based on design
4	Daily Solids Mass TWAS	kg	Float Solids Mass	Based on design
4	Daily Solids Mass Subnatant	kg	Total Mass Subnatant Solids	Based on design

10 WORKED EXAMPLES

10.1   Example 1: Thickening DAF for WAS, no polymer.

The following example is for the design of a DAF unit for thickening of Waste Activated Sludge (WAS).

Table 10-1 sets out the input parameters for the example, the values being quite typical of an actual plant. A float solids concentration (C_F) of 3% is required.

Input parameters	Symbol	Value	Unit
Influent solids concentration (raw water)	SS_{in}	4000	mgTSS/L
Waste liquor flow (raw water flow rate)	Q_i	35	m³/h
Clear water depth required (selected by designer)	d_c	1	m
Saturator pressure	P_{sat}	500	kPa
Air to solids ratio (selected for WAS)	a_s	0.02	
Water temperature	T	27	degrees C
Number of DAF units	No	1	
Saturator efficiency	η_s	60	%
Empirical constants for WAS			
	K_1	231	
	K_2	0.87	
Settling velocity of sludge (indicative)	K_3	1.5	m/h

Table 10-1: Input values for worked example 1 – WAS thickening

The first item to select is the regression equation constants for the design from table 6.4. Select parameters for WAS without polymer.

Constant	Activated sludge
K_4	6.48
K_5	0.2
K_6	0.5
K_7	0.45
K_8	0.76

Table 10-2: Regression equation constants for WAS without polymer

10.1.1 Finding the area of the DAF unit separation zone

The following steps set out the design process:

1. Select appropriate regression equation constants (K_1 to K_8)

2. Select an appropriate air:solids ratio (a_s)

3. Set the required float solids concentration (C_F)

4. Select clear water depth required below total float depth (d_c)

5. Calculate Optimum float depth above water (d_w)

6. Calculate solids loading rate (SLR_{sz})

7. Calculate area required for thickening (A_{SZ})

8. Calculate total float depth ($d_b + d_w$)

9. Calculate tank minimum depth ($d_b + d_w + d_c$)

10. Calculate limiting hydraulic loading or downflow rate (v_L)

11. Calculate actual downflow rate (HL_{SZ}) (after first calculating recycle rate – see §10.1.2 below)

12. Check that $HL_{SZ} < v_L$.   If not, increase A_{SZ} , using HL_{SZ} , redo 8 to 11

13. Check impact of increasing as and r

Calculation

Float depth:

$$d_w = 0.025C_F + 0.19$$
$$d_w = 0.025 \times 3 + 0.19$$
$$d_w = 0.265m$$

Solids loading rate:

$$C_F = K_4.d_w^{K_5}.SLR_{sz}^{-K_6} \Rightarrow SLR_{sz} = \left(\frac{K_4.d_w^{K_5}}{SLR_{sz}}\right)^{\frac{1}{K_6}}$$

$$SLR_{sz} = \left(\frac{6.48 \times 0.265^{0.2}}{3.0}\right)^{\frac{1}{0.5}}$$

$$SLR_{SZ} = 2.74 kg/m^2/h$$

Area required for thickening:

$$A_{sz} = \frac{SS_i.Q_i}{1000.SLR_{sz}}$$

$$A_{sz} = \frac{4000 \times 35}{1000 \times 2.74}$$

$$A_{sz} = 51.1m^2$$

Total float depth:

$$d_b + d_w = d_w\left(1 + K_8.a_s^{-K_7}\right)$$
$$d_b + d_w = 0.265 \times (1 + 0.76 \times 0.02^{-0.45})$$
$$d_b + d_w = 1.436m$$

Minimum tank depth:

$$d = d_b + d_w + d_c$$

$$d = 1.436 + 1$$

$$d = 2.436$$

Limiting downflow rate. (limiting hydraulic loading)

$$v_L = K_1 a_s^{K_1} - K_3$$

$$v_L = 231 \times 0.02^{0.87} - 1.5$$

$$v_L = 6.2 m/h$$

Actual hydraulic loading. (recycle rate to first be calculated – see §9.1.2 below)

$$HL_{SZ} = \frac{Q(1+r)}{A_f}$$

$$HL_{SZ} = \frac{35 \times (1+1.368)}{51.1}$$

$$HL_{SZ} = 1.6 m/h \le v_L \Rightarrow OK$$
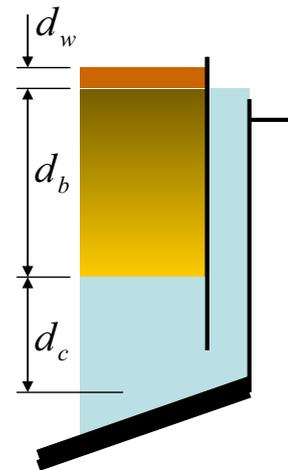
10.1.2 Sizing the recycle system

The following steps set out the design process:

1. Calculate the solubility constant for air at temperature T (S_T)
2. Calculate the mass of air precipitated at temperature T (a_p)
3. Calculate the recycle rate (r)
4. Calculate saturator pump flow rate
5. Select saturator max hydraulic loading (from vendor – say vs = 50m/h for this example)
6. Calculate saturator cross sectional area and diameter
7. Select saturator retention time (say t_s = 60s) and calculate saturator water volume
8. Select water volume to be maintained in saturator (say 75%), and calculate saturator total volume and height

Calculation

Solubility constant:

$$S_T = S_{20} \left(\frac{293}{273+T}\right) . 10^{-500\left(\frac{1}{293} - \frac{1}{273+T}\right)}$$

$$T = 27, \ S_{20} = 0.217$$

$$\Rightarrow \ S_T = 0.195$$

Mass of air precipitated:

$$a_p = S_T P_{sat}$$

$$a_p = 0.195 \times 50 = 97.6 mg/L$$

Recycle rate

$$r = \frac{a_s . SS_{in}}{S_T . P . \eta_s}$$

$$r = \frac{0.02 \times 4000}{0.195 \times 500 \times 0.60} = 1.368$$

Saturator pump flow rate	$Q_r = Q_i.r = 35 \times 1.368 = 47.86\,m^3/h$

Saturator cross sectional area	$A_s = \dfrac{r.Q_i}{v_s} = \dfrac{Q_r}{v_s} = \dfrac{47.8}{50} = 0.957\,m^2$

Saturator water volume	$V = Q_r \times T_s = 47.86 \times \dfrac{60}{3600} = 0.80\,m^3$

Water depth in saturator	$depth = \dfrac{V}{A_s} = \dfrac{0.80}{0.957} = 0.833\,m$

Saturator height	$height = \dfrac{depth}{\%\,full} = \dfrac{0.833}{0.75} = 1.11\,m$

10.1.3 Contact Zone and Cross Flow Area Sizing

The following steps set out the design process:

1. Select the desired hydraulic loading (say HL_{cz} = 120 m/h)   (Ref: Table 3.1)

2. Select the desired residence time (say T_{cz} = 60s)   (Ref: Table 3.1)

3. Select the cross flow velocity (say v_{cf} = 90m/h)   (Ref: Table 3.1)

4. Adopt the recycle rate (r) as previously calculated and determine the flow through the contact zone ($Q_{cz} = Q_i + rQ_i$)

5. Adopt a maximum float layer thickness as previously calculated in § 10.1.1 (d_w = 0.265m)

6. Calculate the contact zone area (A_{cz}) and diameter

7. Calculate the contact zone depth (d_{cz}) (should be 2<d_{CZ}<4 m   (Ref: Table 3.1)

8. Calculate the cross flow area (A_{cf})

9. Calculate the cross flow depth (d_{cf})

10. Calculate the combined depth of the contact zone, cross flow area and float depth above the water ($d_{cz} + d_{cf} + d_w$)

11. Check that this is smaller than the tank depth previously calculated (§ 10.1.1)

Calculation

Flow through
Contact zone

$$Q_{cz} = Q_i + rQ_i = 35 + 47.86 = 82.86 m^3/h$$

Contact zone area

$$A_{cz} = \frac{Q_{cz}}{v_{cz}} = \frac{82.86}{120} = 0.691 m^3$$

and diameter

$$diameter = \sqrt{\frac{4 \times A_{cz}}{\pi}} = \sqrt{\frac{4 \times 0.691}{\pi}} = 0.938 m$$

Depth of contact zone

$$d_{cz} = \frac{Q_{cz}.T_{cz}}{A_{cz}} = \frac{82.86}{0.691} \times \frac{60}{3600} = 2.00 m \geq 2.0 m \Rightarrow OK$$

Cross flow area

$$A_{cf} = \frac{Q_{cz}}{v_{cf}} = \frac{82.86}{90} = 0.921 m^2$$

Cross flow depth

$$d_{cf} = \frac{A_{cf}}{\pi \times diameter} = \frac{0.921}{\pi \times 0.938} = 0.313 m$$

Combined depth

$$depth = d_{cz} + d_{cf} + d_w$$
$$= 2.0 + 0.313 + 0.265$$
$$= 2.578 \geq 2.436 \Rightarrow unacceptable$$

This is an unacceptable result (compare result in Section 10.1.1).

- In this case, the depth of the tank needs to be increased to achieve 2.578 at the contact zone.
- Check this against tank geometry to see what is required.
- In a rectangular tank it may be necessary to only increase the depth of the contact zone.
- In a circular tank, the conical floor may give the designer the extra depth that is required.

> *It should be noted that the DAF tank dimensions in this example have been calculated to the nearest millimetre (mm). This has been done for the purpose of the example, and illustration. The empirical methods used here are not capable of that level of accuracy, and in practice final dimensions should be rounded to the nearest 100mm.*

10.2 Example 2: Thickening DAF for WAS, with polymer

Using the information from example 1 assuming the facility is upgraded for polymer dosing, determine:

1. The new (increased) solids loading rate that can be applied
2. The anticipated float solids concentration
3. Whether other components of the facility are adequately sized

Inputs:

1. Previous inputs are unchanged except for the regression equation constants. These can be selected from table 6.4 – repeated in table 10.3 below.

2. Area of the separation zone from previous calculation $A_{sz} = 51.1m^2$

Constant	Activated sludge
K_4	11.22
K_5	0.22
K_6	0.4
K_7	0.45
K_8	0.5

Table 10-3: Regression equation constants for WAS with polymer

Answer

There is no single answer to this question. It all depends on the desired outcome. For a particular float solids concentration (C_F), a raw water flow (Q_i) and solids loading rate in the separation zone (SLR_{sz}) can be determined. The calculations are similar to those used in example 1, and not repeated here, but to illustrate what can be achieved a series of calculations have been completed assuming a range of float solids concentrations (C_F). The results are tabulated below, with a graphical solution (Figure 10.1) to illustrate the outcome.

The approach used here is to:

1. Select a series of float solids concentrations (3.0, 3.5, 4.0, …6.0)

2. Determine the corresponding SLR_{sz} and raw inflows (Q_i) to achieve the SLR_{sz} in the 51.1m² DAF

3. The hydraulic loading limit remains unchanged on $v_L = 6.2$m/h

4. Showing these points graphically and then selecting an operating point in line with what is desired is the best approach.

5. The recycle rate remains constant at 1.37. Note that this is 1.37×Q_i so the actual Q_r varies accordingly.

6. For the selected conditions, check that:

   a. The hydraulic loading rate in the separation zone v_L is not exceeded, and preferably with some margin of safety.

   b. The contact zone is still adequately sized.

   c. The cross flow area is still adequate.

   d. That the saturator and recycle system are adequately sized.

Float solids (C_F) %	SLR_{sz} kg/m²/h	Raw inflow Q_i m³/h	Contact zone area m²	Depth of cross flow area m	Saturator pump flow rate L/s
3.0	13.0	166.5	3.030	0.638	63.2
3.5	9.1	116.1	2.114	0.533	44.1
4.0	6.7	85.2	1.551	0.457	32.3
4.5	5.1	65.0	1.183	0.399	24.7
5.0	4.0	51.0	0.929	0.354	19.4
5.5	3.2	41.1	0.748	0.317	15.6
6.0	2.6	33.8	0.614	0.287	12.8

Table 10-4: Tabulation of results for example 2

Interpreting information from Table 9.4 for the DAF operated with polymer

1. The contact zone area calculated in example 1 is 0.92m². Looking to table 10.4 (circled in red) this area now corresponds with a raw inflow of 51m³/h, and a float solids concentration of about 5.0%. The contact zone hydraulic loading rate is still 130m/h as per example 1. From table 3.1 the hydraulic loading rate could be increased to as much as 200m/h but caution is advised at this limit. Increasing the contact zone hydraulic loading rate to 160m/h (calculations not shown) will increase the raw inflow to about 65m³/h, but the float solids concentration will drop to 4.5%.

2. The cross flow depth previously calculated is 313mm. Looking to table 10.4 (circled in blue) this depth corresponds with a raw inflow of 41.1m³/h. It is based on a cross flow velocity of 100m/h. From table 3.1, this too can be increased, with the upper limit being 200m/h, and again, caution is advised. By also increasing the cross flow velocity to 160m/h (calculations not shown) the hydraulic loading rate can be increased to about 85m³/h. Further checks should be undertaken to see if the hydraulic loading on the contact zone can be increased to match this, but noting that the penalty will be a drop in anticipated float solids concentration.

3. Further checks will reveal that a larger saturator and increased saturator pump flow rate will be required.

The lesson from the above is that it is not simply a matter of adding a polymer system to a DAF unit without checking that the other elements of the DAF unit can also cope with the increased flow and loading.

Note: The graphical representation shown in Figure 10.1 must be read in the context of the comments above.
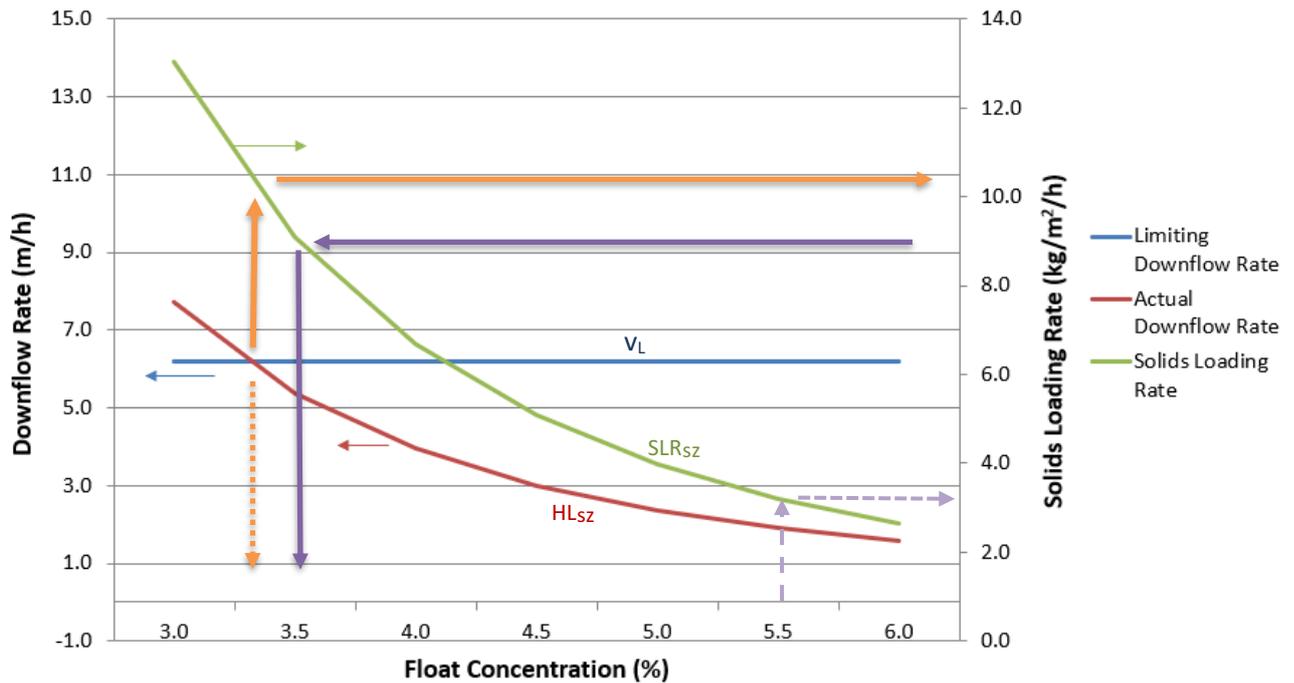
Figure 10-1: Graphical solution showing v_L, HL_{sz} and SLR_{sz} vs float concentration C_F for a 51.1m² DAF

Interpreting the graph

1. Where the hydraulic loading rate (HL_{sz}) (red line) exceeds the limiting downflow rate (v_L) (blue line) the DAF will fail. Where the 2 curves intersect, following the orange arrow upwards indicates that a SLR_{sz} of about 10.1kg/m²/h is where the failure envelope is reached.

2. Selecting a SLR_{sz} of 9.0kg/m²/h would be a safer option and give a float solids of about 3.5% (follow purple line)

3. If a higher float solids concentration is desired (say 5.5%) then the solids loading rate should be limited to about 3.3kg/m²/h (follow broken mauve line)

10.3   Example 3: Clarification of algae rich water

The following example is for the design of a DAF unit for clarification of maturation pond water from a waste stabilisation pond (WSP) treatment plant. Assume that ferric chloride ($FeCl_2$) is used as a flocculent. Assume a rectangular DAF with a width of $W_{DAF} = 1.7m$

Table 10.5 sets out the input parameters for the example.

Input parameters	Symbol	Value	Unit
Influent solids concentration (raw water)	SS_{in}	150	mgTSS/L
Ferri-chloride dose rate (from lab trials)		40	mg/L
Waste liquor flow (raw water flow rate)	Q_i	50	m³/h
Clear water depth required (selected by designer)	d_c	0.5	m
Saturator pressure	P_{sat}	450	kPa
Air volume concentration	C_{vol}	8.0	mL/L
Altitude (assume close to sea level)		0.0	m AHD
Water temperature	T	27	degrees C
Number of DAF units	No	1	
Saturator efficiency	η_s	75	%
HLR on contact zone (designer selected)	HL_{CZ}	62	m/h
Contact time in contact zone (designer selected)	T_{CZ}	144	s
Cross flow velocity (designer selected)	v_{cf}	35	m/s
Safety factor for separation zone area	S_f	1.2	-
Empirical constants for algae (used only to determine v_L)			
	K_1	330	
	K_2	0.77	
Settling velocity of algae (indicative)	K_3	0.0	m/h

Table 10-5: Input values for worked example 3 – Clarification of WSP effluent

10.3.1   Chemical dosing and total suspended solids

$$FeCl_3 + 3H_2O \rightarrow Fe(OH)_3 + 3H^+ + 3Cl^-$$
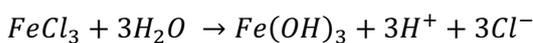
Molecular weights:

MW of $FeCl_3$ 162.3

MW of $Fe(OH)_3$ 106.8

Dose rate   40mg/L

Total solids

$$Fe(OH)_3 \ (solids) = 40 \times \frac{106.8}{162.3} = 26.3 \ mg/L$$

Raw water suspended solids = 150mg/L (given)

Total Suspended Solids = $150 + 26.3 = 176.3 mg/L$

10.3.2 Sizing the recycle system

The following steps set out the design process:

1. Calculate the solubility constant for air at temperature T (S_T)

2. Calculate the mass of air precipitated at temperature T (a_p)

3. Find the air mass concentration from figure 5.4

4. Calculate the recycle rate (r)

5. Calculate the minimum air:solids ratio (a_s) and select a_s ratio for design

6. Calculate saturator pump flow rate (Q_r)

7. Select saturator max hydraulic loading (from vendor – say v_s = 50m/h for this example)

8. Calculate saturator cross sectional area and diameter

9. Select saturator retention time (say t_s = 60s) and calculate saturator water volume

10. Select water volume to be maintained in saturator (say 85%), and calculate saturator total volume and height

Calculation

Solubility constant:
$$S_T = S_{20} \left(\frac{293}{273+T}\right) . 10^{-500\left(\frac{1}{293} - \frac{1}{273+T}\right)}$$

$T = 27°C, \ S_{20} = 0.217$

$\Rightarrow \ S_T = 0.195 \ mg/L/kPa$

Mass of air precipitated
$a_p = S_T . P_{sat}$

$a_p = 0.195 \times 450 = 87.8 mg/L$

Mass air concentration
From fig 4.4 air mass concentration ≈ 9.5mg/L

Recycle rate
$$r = \frac{C}{S_T \cdot P \cdot \eta_s}$$

$$r = \frac{9.5}{0.195 \times 450 \times 0.75} = 0.144$$

Air:solids ratio
$$a_s = \frac{r.S_T.P.\eta_s}{SS_{in}} = \frac{0.144 \times 0.195 \times 450 \times 0.75}{76.3} = 0.125$$

Select a_s = 0.13

Saturator pump

flow rate $\qquad Q_r = rQ_i = 0.144 \times 50 = 7.2 m^3/h$

Saturator cross
sectional area $\qquad A_s = \frac{r.Q_i}{v_s} = \frac{Q_r}{v_s} = \frac{7.2}{50} = 0.144\ m^2$

Saturator water
Volume $\qquad V = Q_r \times T_s = 7.2 \times \frac{100}{3600} = 0.2 m^3$

Water depth in
saturator $\qquad depth = \frac{V}{A_s} = \frac{0.2}{0.144} = 1.39 m$

Saturator height $\qquad height = \frac{depth}{\%\ full} = \frac{1.39}{0.85} = 1.63 m$

10.3.3 Sizing the contact zone and cross flow height

The following steps set out the design process:

1. Calculate the contact zone plan area (A_{cz})

2. Calculate the contact zone width (W_{cz}) (see fig 3.4) ($W_{DAF} = 1.7m$)

3. Calculate the height of the contact zone (Hcz) (see fig 3.4) (this is likely to be the minimum depth of the DAF unit)

4. Calculate the volume of the contact zone (above the recycle release)

5. Calculate the cross flow height

Contact zone area $\qquad A_{cz} = \frac{(1+r)Q_i}{HL_{cz}} = \frac{(1+0.144) \times 50}{62} = 0.918 m^2$

Contact zone width $\qquad W_{cz} = \frac{A_{cz}}{W_{DAF}} = \frac{0.918}{1.7} = 0.54 m$

Contact zone height $\qquad H_{cz} = HL_{cz}.T_{cz} = \frac{62 \times 144}{3600} = 2.49 m$

Contact zone volume $\qquad V_{cz} = A_{cz}.L_{cz} = 0.918 \times 2.49 = 2.29 m^3$

Cross flow height $\qquad H_{cf} = \frac{(1+r)Q_i}{v_{cf}.W_{DAF}} = \frac{(1+0.144) \times 50}{35 \times 1.7} = 0.96 m$

10.3.4 Sizing the separation zone

The following steps set out the design process:

1. Calculate the limiting hydraulic loading rate (v_L)

2. Calculate the separation zone area applying the safety factor (A_{SZ})

3. Calculate the actual hydraulic loading rate (HL_{SZ})

4. With the width given calculate the length of the separation zone

5. Calculate the solids loading rate

Calculation

Limiting HLR

$$v_L = K_1 . a_s^{K_2} - K_3 = 68 \times 0.13^{0.91} - 0 = 10.6 m/h$$

Separation zone area

$$A_{SZ} = \frac{S_f . Q_i (1+r)}{v_L} = \frac{1.2 \times 50 \times (1+0.144)}{10.6} = 6.46 m^2$$

Hydraulic loading rate

$$HL_{SZ} = \frac{Q_i . (1+r)}{A_{sz}} = \frac{50 \times (1+0.144)}{6.46} = 8.9 m/h$$

Length of separation zone

$$L_{SZ} = \frac{A_{SZ}}{W_{SZ}} = \frac{6.46}{1.7} = 3.8 m$$

Solids loading rate

$$SLR_{SZ} = \frac{TSS . Q_i . (1+r)}{1000 . A_{SZ}} = \frac{76.3 \times 50 \times (1+0.144)}{1000 \times 6.46} = 0.68 kg/m^2/h$$

Overall dimensions of the facility would be:

Length: $0.54 + 3.80 = 4.34m \ plus \ wall \ thicknesses$

Breadth: *Selected as* $1.7m$ *to which must be added wall thicknesses*

Water depth: $2.49m \ plus \ freeboard \ of \ about \ 0.3m$

APPENDIX A

Referenced Resources and Documents

An understanding of DAF technology for clarification operations, especially for drinking water applications, has shown significant growth over the past 30 years. However, the work done in the 1970's by Bratby and Marais, with refinements by Haarhoff in 1993 and 1998, remains the best basis for design of DAF thickening of WAS. Relevant references are listed below.

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APPENDIX B

Preferred Terminology

The table below contains preferred terms for use by the Designer in Corporation mechanical designs.

Preferred Terminology Units	Non-preferred
Bend	Elbow
Discharge (pump)	Delivery, outlet
Drinking water	Potable water
Ejector	Injector
GRP	FRP
Impeller	Impellor
L/s	l/s
MLD	ML/d, Ml/d
Nominal diameter - DN	ND
Non return valve	Check valve
Pumpset	Pump unit, pumping unit
Pump station	Pumping station
Sewage pump station	Wastewater pump station
Suction (pump)	Inlet, intake

APPENDIX C

Abbreviations, acronyms and symbols

The table below contains terms and symbols used in this Guideline and more generally in the water industry.

Term	Description
AADF	Average Annual Daily Flow = the total annual flow reaching the WWTP in a calendar year divided by 365. It is useful for understanding annual plant throughput but should not be used as a basis for process design as it includes flows from wet weather events. For process design purposes ADWF and PDWF should be used.
ADWF	Average Dry Weather Flow = the average flow of incoming used water measured in the three driest (non-rainfall) months of the year.
ABS	Acrylonitrile – Butadiene – Styrene (pipe and fittings)
AHD	Australian Height Datum
AISI	American Iron and Steel Institute
ANSI	American national Standards Institute
API	American Petroleum Institute
AS	Australian Standards
ASM	American Society of Metals
ASME	American Society of Mechanical Engineers
ASTM	American Society for testing and Materials
AWS	American Welding Society
BEP	Best Efficiency Point
BFJ	Butt-fusion joint
BJ	Butt joint (plain ends)
BOD	Biochemical oxygen demand
BS	British Standard
BSP	British Standard Pipe
BSI	British Standards Institute
BWL	Bottom Water Level
CI	cast Iron
CIP	Clean-in-place
CML	Cement mortar lined
COD	Chemical oxygen demand

Term	Description
CS	Carbon steel (pipe)
CSA	Canadian Standards Association
©	Copyrighted
Cv	Flow coefficient, flow factor or valve coefficient (imperial)
dBA	Decibel – A weighted scale
DI	Ductile Iron (pipe and fittings)
DICL	Ductile iron cement lined
DIN	Deutsches Institut fur Normung (Germany)
°C	Degrees Celsius
DN	Nominal diameter
EAS	Excess activated sludge
EFJ	Electro-fusion joint
EPDM	Ethylene propylene diene monomer rubber
ESJ	Elastomeric seal joint
FAD	Free air delivered
FBE	Fusion bonded epoxy
FJ	Flange joint (bolted)
FRP	Fibreglass reinforced plastic
g	Acceleration due to gravity – 9.81 m/s^2
GDA	Geocentric datum of Australia
GL	Gigalitres
GRP	Glass reinforced plastic (pipe)
HBW	Brinell hardness number
HDPE	High density polyethylene
HGL	Hydraulic Grade Line
H	Head of water in m
Hz	Hertz (cycles per second)
h	Hour
HRB	Rockwell B (hardness)
HRC	Rockwell C (hardness)
IEC	International Electrotechnical Commission
IFJ	Flush joint

Term	Description
I/O	Input/Output
IRHD	International rubber hardness degree
ISO	International Standards Organisation
JIS	Japanese Industrial Standard
k	Absolute pipe roughness in mm
K	Resistance coeeficient
kg	Kilogram
kL	Kilolitre
kN	Kilonewton
kPa	Kilopascal
Kv	Flow coefficient, flow factor or valve coefficient (metric)
kW	Kilowatt
L	Litre
L/s	Litres per second
m	Metre
m^2	Square metres
m^3	Cubic metres
mm	Millimetre
m/s	metres per second
MDPE	Medium density polyethylene
ML	Megalitre
MLD	Megalitres per day
MLSS	Mixed liquor suspended solids
MSCL	Mild steel cement lined (pipe and fittings)
N	Speed in revolutions per minute
NACE	National Association of Corrosion Engineers
NATA	National Association of Testing Authorities
NDT	Non-destructive testing
NEMA	National Electrical Manufacturers Association
NFPA	National Fire Protection Association
Nm	Newton metres
NPSH	Net positive suction head

Term	Description
NPSHa	Net positive suction head available
NPSHr	Net positive suction head required
NZS	New Zealand Standards
OEM	Original equipment manufacturer
OH&S	Occupational health and safety
O&M	Operations and maintenance
PE	Polyethylene (pipe)
PDWF	Peak Dry Weather Flow applies to the daily diurnal flow pattern. As a factor, it is the ratio of the peak hourly flow (usually late morning) to the ADWF measured in the three driest (non-rainfall) months of the year (Usual range is 1.5 to 2.0).
P&ID	Piping & Instrumentation Diagram
PFD	Process Flow Diagram
pH	Measure of acidity/alkalinity (from German *potenz* = power, and *H*; the symbol for hydrogen). A logarithmic index for the hydrogen ion concentration in an aqueous solution.
PLC	Programmable logic controller
PN	Nominal pressure
ppm	Parts per million
PU	Polyurethane
PVC	Polyvinyl chloride
PWWF	Peak Wet Weather Flow is usually caused by infiltration of water into the collector system during rainfall events. It can be of short (one hour) or long (days) duration. As a design factor it is the ratio of the peak hour flow reaching the plant to the ADWF. (Usual range is 1.9 to 2.2 for Metro plants). To be used for hydraulic design.
Q	Flowrate, capacity or discharge rate
®	Registered
RCD	Residual current joint
Re	Reynolds number
rpm	Revolutions per minute
RPS	Raw primary sludge
RPZD	Reduced pressure zone device
RRJ	Rubber ring joint
s	Second
RST	Rotary screw thickener

Term	Description
SANZ	Standards New Zealand
SCADA	Supervisory control and automated data acquisition
SI	Systems International d' Unites
SLR	Solids loading rate
SPS	Strategic Product Specification
SS	Stainless steel
SSJ	Spherical slip-in welded joint
SWJ	Solvent welded joint
TDH	Total developed head in metres
TEAS	Thickened excess activated sludge (= TWAS)
™	Trademark
TOC	Total organic carbon
TSS	Total suspended solids
TWL	Top Water Level
uPVC	Unplasticized Polyvinyl Chloride (pipe and fittings)
UV	Ultraviolet
V	Volts
VSD	Variable speed drive
VVVF	Variable voltage variable frequency drive (= VSD)
WLL	Working load limit (replaces SWL)
WAS	Waste activated sludge (= EAS)
WSAA	Water Services Association of Australia
WTIA	Welding Technology Institute of Australia
WRRF	Water Resource Recovery Facility
WWTP	Wastewater Treatment Plant

APPENDIX D

The table below contains standard units and relationships used by the Corporation.

Quantity	Unit	Relationship
Flow	L/s	Rate of flow
	MLD	L/s x 86.4
Volume	L	Amount of volume
	kL	L / 10^3
	ML	L / 10^6
	GL	L / 10^9
Length	mm	Linear dimension
	m	mm / 10^3
Area	m^2	Areal measure
	ha	m^2 / 10^4

The table below lists SI unit prefixes and symbols for reference.

Fraction or Multiple	Prefix	Symbol
10^{-1}	Deci	d
10^{-2}	Centi	c
10^{-3}	Milli	m
10^{-6}	Micro	μ
10^{-9}	Nano	n
10^{-12}	Pico	p
10	Deca	da
10^2	Hecta	h
10^3	Kilo	k
10^6	Mega	M
10^9	Giga	G
10^{12}	Terra	T

END OF DOCUMENT