Scum formation in a nutrient removing activated sludge plant

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Abstract

Under certain conditions air entrainment is identified as a major contributing cause to scum build-up at the Johannesburg Northern Works. Under normal operating conditions the relative proportions of filamentous organisms in the MLSS and scum remained unchanged and neither *Microthrix parvicella* nor *Nocardia* were found to predominate. Introduction of sludge recycling in the primary clarifiers caused scum to consist almost entirely of *Microthrix parvicella*. It is suggested that bubble strength may be promoted by the biological production of chemicals that promote film stability and that bubbles collapse when these film strengtheners are removed by syndets.

Introduction

The formation of scum on the surface of activated sludge has been observed on numerous plants throughout the world. If this scum is retained within the plant it does not cause any serious problems, although it may result in the entire surface being covered, thus reducing the area open to the atmosphere, which could result in less efficient oxygen transfer if surface aerators are used. Effluent quality will obviously suffer when scum passes over the final clarifier weirs.

Jenkins *et al.* (1984) have examined activated sludge derived scums and shown them to contain predominantly either *Nocardia* or *Microthrix parvicella*.. These filamentous bacteria have the ability to bridge floc particles and it is furthermore hypothesised that they have cell walls that allow bubble attachment which, when significant enough, may ultimately cause flotation of floc to form a scum. Eikelboom (1982) maintains that these filamentous bacteria generally contain large quantities of lipids which decrease their density in relation to water and cause them to rise to the surface of the reactor. Since scum formation was prevalent at the Johannesburg Northern Wastewater Purification Works, an in-depth study was conducted to ascertain the cause and extent of the problem.

Scum formation at the Northern Works

This works has three identical 50 Mℓ/d activated sludge modules based on the Bardenpho process for biological nutrient removal as depicted in Figure 1.

Surface aerators are used in both aerobic zones. The MLSS recycle from the primary aerobic reactor to the primary anoxic reactor is by means of axial flow pumps and Archimedian screw pumps are employed in the recycling of return sludge.

At the time these observations were made scum was present on the plant and varied from a light, frothy, texture (Figure 2a) to a heavy, mucoid, mass (Figure 2b). The colour range was from cream to brown, becoming black and crusty on standing (Figure 2d). It occurred as discreet islands (Figure 2e) or as a blanket covering the entire surface (Figure 2f). In the aerobic zone it formed a thin layer of foam in quiescent areas where the aerators were switched off. The scum under investigation had been present in fairly large amounts throughout the previous drought-stricken summer. As previously stated *Nocardia* or *Microthrix parvicella* are usually associated with scum formation and the aim of the study was to identify the specific causative agent at the Northern Works and relate its growth to operational parameters.

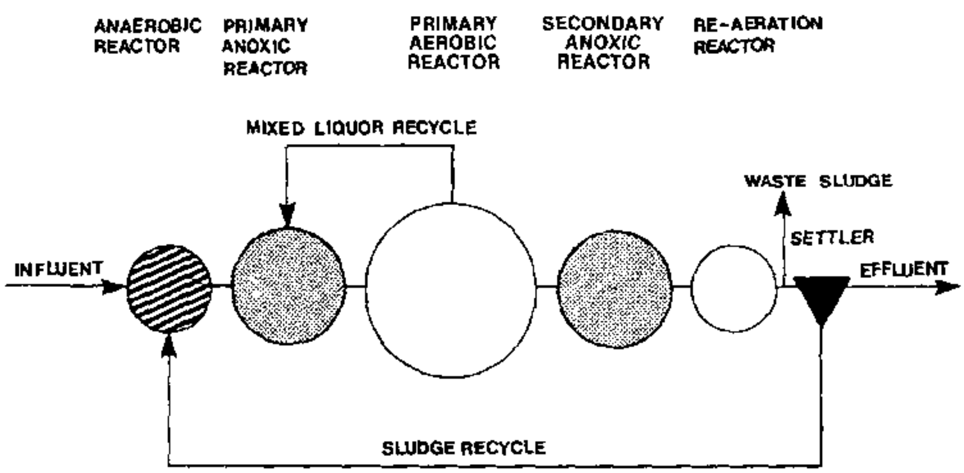

Figure 1
Five-stage Bardenpho biological nutrient removal process.

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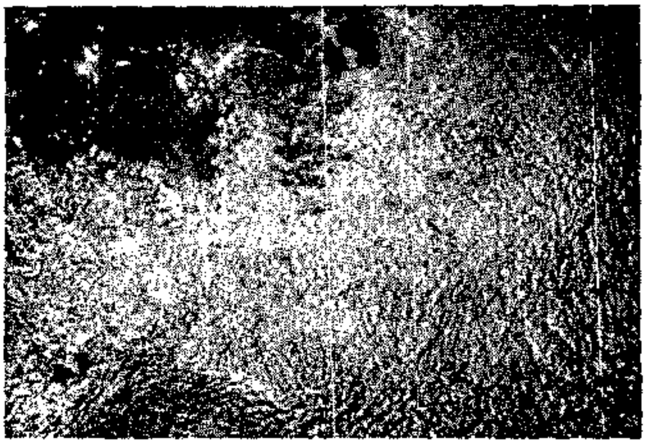


Figure 2a
Light frothy scum

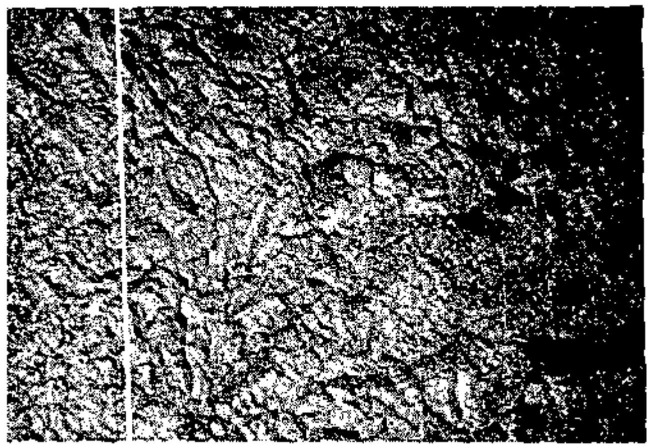


Figure 2b
Heavy mucoid scum

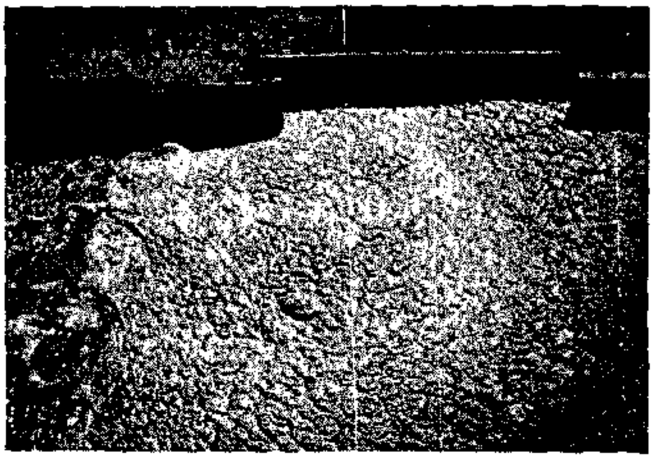


Figure 2c
Cream to brown coloured scum

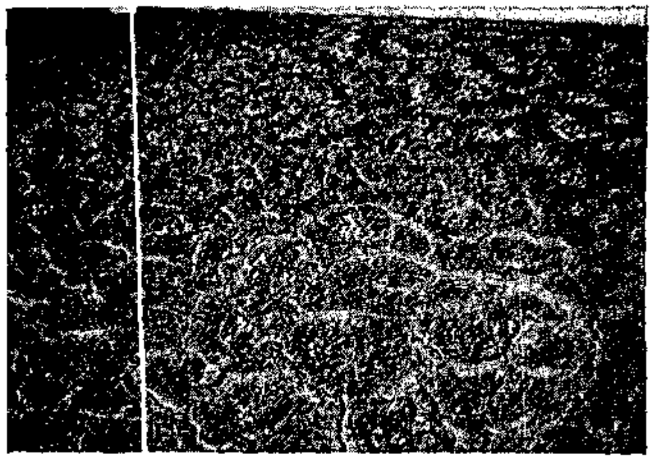


Figure 2d
Black and crusty scum

Figure 2e
Discreet islands of scum

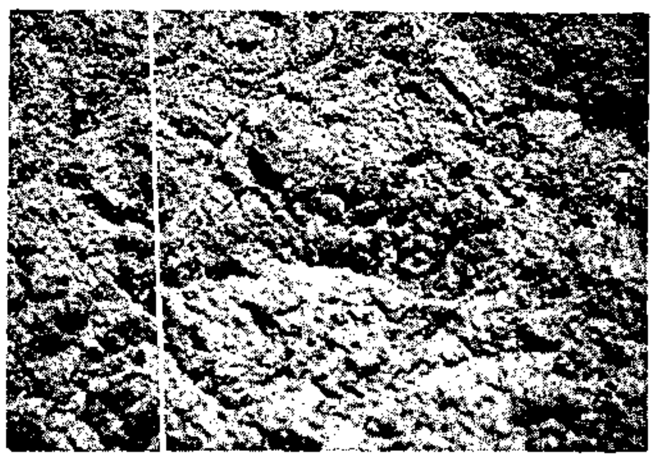


Figure 2f
Scum covering entire surface

Identification of the filamentous bacteria present

Eikelboom and Van Buijsen (1981) developed a key for the identification of filamentous bacteria. Using this key the filaments occurring in the reactors, as well as in the scum, were identified. The results are shown in Table 1.

According to Jenkins *et al.* (1984) these filaments are all indicative of a low food to micro-organism ratio, which is indeed the case at the Northern Works where the sludge age was approximately 25 days at the time of this investigation. Worthy of note in Table 1 is that both *Nocardia* and *Microthrix parvicella* were present in small numbers.

TABLE 1
FILAMENTOUS BACTERIAL POPULATION AT NORTHERN WORKS

Filament	Quantity	
0803	Figure 3a	Abundant
0041	Figure 3b	Few
0675	Figure 3c	Scanty
0092	Figure 3d	Few
Nocardia	Figure 3e	Scanty
Microthrix parvicella	Figure 3f	Scanty

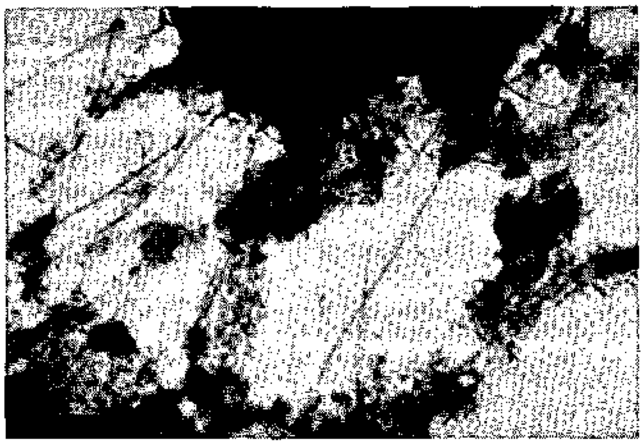


Figure 3a
Gram stain of 0803 (Eikelboom)

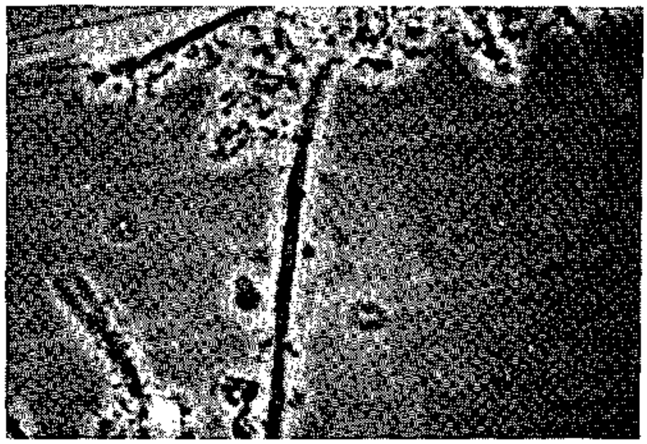


Figure 3b
Phase contrast of wet preparation of 0041 (Eikelboom)

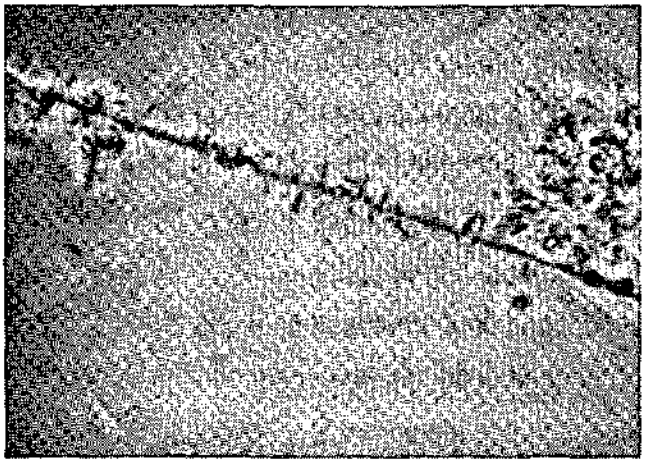


Figure 3c
Phase contrast of wet preparation of 0675 (Eikelboom)

Figure 3d
Neisser stain of 0092 (Eikelboom)

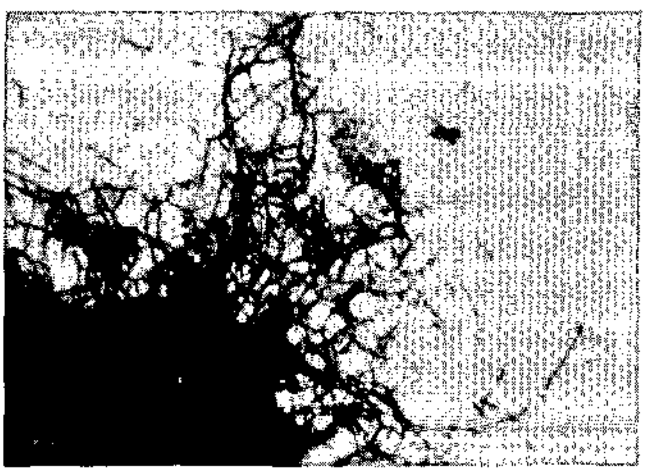


Figure 3e
Gram stain of ***Nocardia***

Figure 3f
Gram stain of ***Microthrix parvicella***

This was totally unexpected as Eikelboom *et al.* (1981) have suggested that if scum is formed, one of these two filaments generally occurs in abundance.

Another interesting point was that there appeared to be no difference in the relative numbers of filamentous organisms present in the bulk of the liquid and the scum, thus indicating that no selective concentration was taking place in the foam.

The same situation however, did not apply to the *Acinetobacter* population. Slides stained by Gram's method (Cruikshank, 1960) showed these aerobic bacteria to be more swollen and clustered (Figure 4b) in the scum, while in the MLSS they appeared concave and occurred not in clusters, but as single bacilli (Figure 4a).

Physical characteristics of scum

Examinations under stereo-microscope

Beneath a dark, dried-out surface film the scum was found to contain a myriad of tiny bubbles coated with sludge giving an overall honeycomb appearance. The walls of these bubbles were gelatinous in nature and when pierced, the skin would fold back upon itself and a stable, hollowed out aperture would be formed, there being no flow of material back into the cavity thus formed. This phenomenon was particularly noticeable when the scum had thickened.

The fragile light bubbles in the froth from the aerobic zone were easily broken and the contents were very fluid. The clusters of bubbles from the surface of the final clarifiers which resembled a white net-like structure (Figures 4c and 4d) were found to be difficult to puncture.

Gas production within the sludge

Routine samples of activated sludge taken from the plant for microbiological analysis were seen to contain large quantities of gas which had lifted the entire solids content to the surface of the jar. At the time this was noted, no nitrates were present, so it was concluded that the gas present was not nitrogen.

The pH of the activated sludge was 7,2 thus minimising the possibility of this gas being carbon dioxide. The absence of deep anaerobiosis, black colouration and lumpy appearance of the sludge was not indicative of methane production.

The conclusion reached was that the gas present must be air.

Plant observations

The visual appearance of the scum on the surface of all the reactors of one module at the Northern Works was monitored to ascertain what operational conditions caused the scum to proliferate and under what conditions it disappeared. A few of the more interesting observations were as follows:-

- Hosing down of scum on the surface of the clarifiers decreased the thickness dramatically and changed a dark cream scum into a black, wet, leathery-looking mass.
- Heavy rains one evening reduced a mucoid blanket of scum 200 mm in depth, which covered the entire surface of the anaerobic zone, into fragmented islands about 40 mm in depth. Within a few days the original appearance had once more manifested itself.
- The speed with which the scum could be formed was noted when normal working conditions were resumed on a module which had been switched off for a week. Scum which had become black, extremely hard and crusty at the surface of the internal sludge recycle channel (Figure 4e) was cracked and broken up by the cascading discharge from the internal MLSS recycle. It was interesting to note the disruptive force of the entrained air as it escaped upward through the dark-coloured crust (Figure 4f) replacing it with a frothy cream-coloured scum (Figure 4g).

  Visual study of the plant showed the massive entrainment of air was taking place at the following points : at the discharge of the internal recycle pumps; at the discharge of the Archimedian screw pumps returning sludge from the final clarifiers back to the biological reactor; and at the overflow weirs at the end of the aerobic zones (Figure 6e).

The bubble rich scum leaving these areas returns to the following quiescent areas: the first anoxic zone (Figure 6c and d); the return sludge channel to the anaerobic zone; the second anoxic zone; and the final clarifiers.

In these quiescent zones the entrapped air does not readily separate from the sludge and the high film strength of these bubbles permits the slow build-up of large floating rafts of solids which ultimately take on the characteristic scum-like appearance.

At the Northern Works most of the inter-zone connections are sub-surface and with baffles running the entire width of the plant, the scum simply cannot escape and therefore accumulates. Flow into these quiescent zones usually follows the same pattern. The residual velocity of the influent flow containing entrained air causes the incoming solids/air mixture to pack up against the existing scum, compressing it into a more compact form.

Areas of differing ages of scum were clearly seen, the older scum being the compact, dark, raised portions and the newer scum the light, loose-looking portion (Figure 5a). The back flow of the scum from the aerobic into the anoxic zones was clearly seen as semi-circular whirls attaching themselves to the existing scum (Figure 5b). Worthy of note was the elastic appearance of the large bubbles in both the return sludge channels (Figures 6f, 5c).

Table 2 reflects performance data for this plant when experiencing problems with scum formation. It will be noted

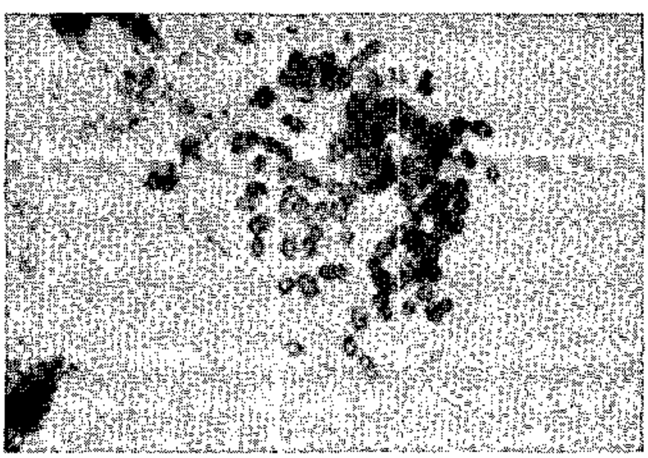


Figure 4a
***Acinetobacter** in activated sludge in anaerobic zone*

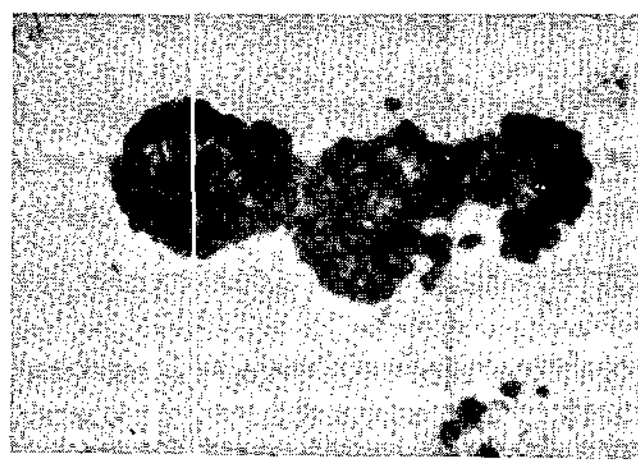


Figure 4b
***Acinetobacter** present in scum in anaerobic zone*

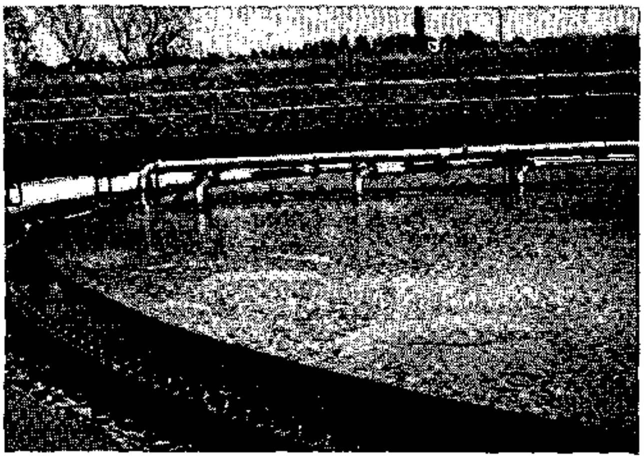


Figure 4c
Net-like structure of scum on surface of secondary clarifiers.

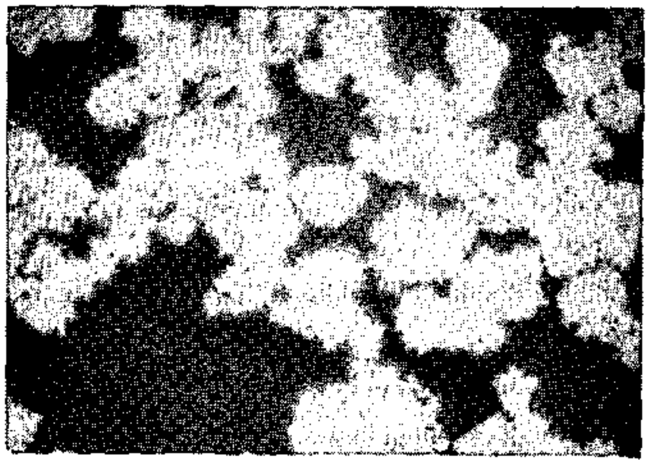


Figure 4d
Close up of net-like structure of scum on surface of secondary clarifiers

that good removals of both nitrogen and phosphorus were being achieved at the time.

Discussion

Eikelboom (1977), and Jenkins *et al.* (1984) have shown that the microbial composition of scums on activated sludge plants can be reasonably predicted from the food to micro-organism loading on the plant. The observations described in this presentation tend to contra-indicate this hypothesis and suggest that scum formation may be due solely to the entrainment of air. Biosurfactant production by *Nocardia erythropolis* has been noted by Margaritis *et al.* (1979) and Sar and Rosenberg (1983), have reported on the extracellular production of bio-emulsifiers by 16 different strains of *Acinetobacter calcoaceticus.* It is suggested that such substances may well be produced in the scum layers of nutrient removing plants and impart tremendous strength and stability to entrained air bubbles. Under these circumstances, no enhancement of a particular filamentous bacterial species in the scum was noted.

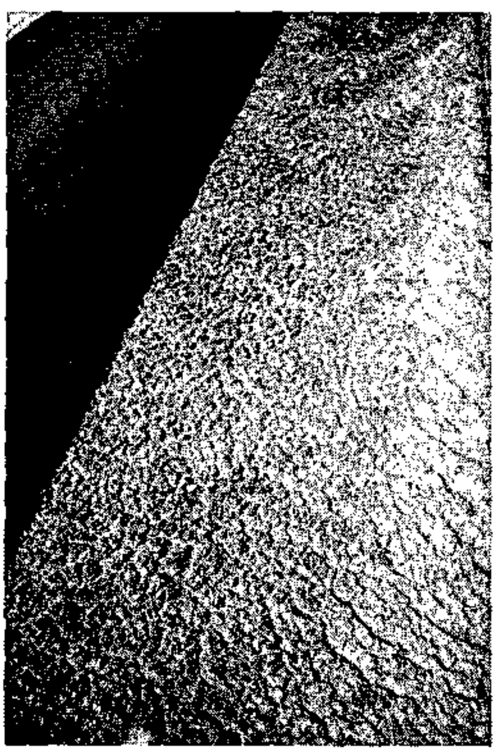


Figure 4e
Hard crusty scum on surface of sludge return channel

Figure 4f
Fresh scum breaking through hard layer of sludge on surface of sludge return channel

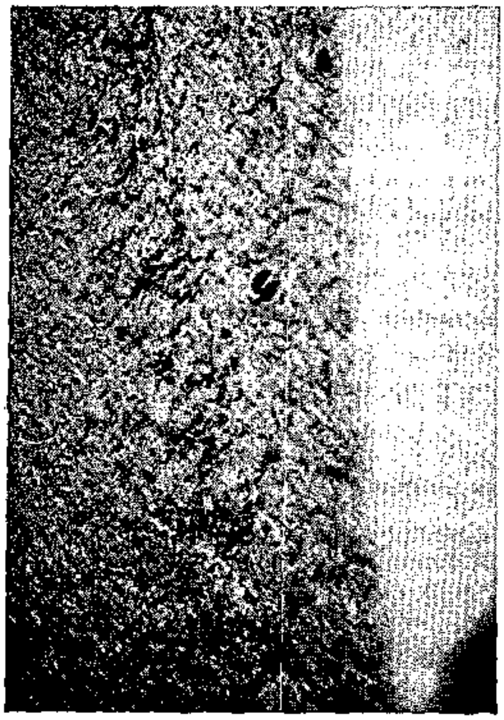


Figure 4g
Final mucoid appearance of scum on surface of sludge return channel

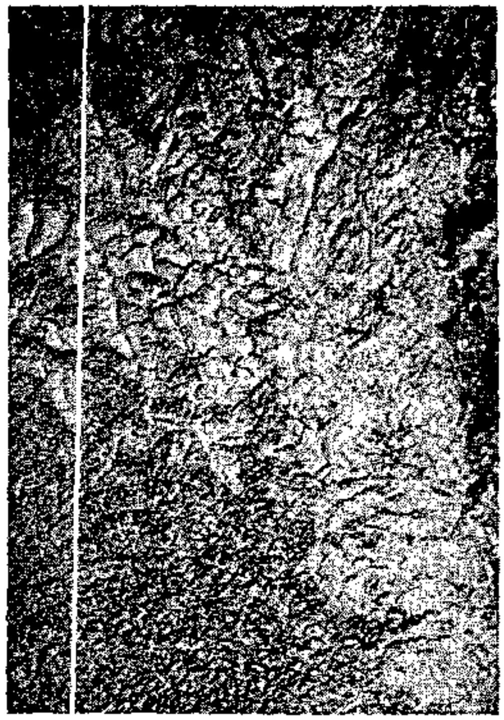


Figure 5b
Areas of different composition in scum layer. The light bubbly texture of newly-formed scum attaching to the more mucoid form is seen at the left of the picture. Older scum is visible at the upper right-hand corner and scum of even greater age is visible in the lower right of the picture

At the time when these observations were made the plant was operated as indicated in Figure 1 and was carrying an excessive amount of MLSS due to problems with the waste sludge disposal system. The Feed: Micro-organism (F/M) ratio under these circumstances was 0,06. In a later experiment, not described here, raw sludge recycling was introduced on the primary clarifiers and after a few weeks, a dramatic change in the microbial composition of the scum layer was noted as it then consisted almost entirely of *Microthrix parvicella*. Obviously the chemical characteristics

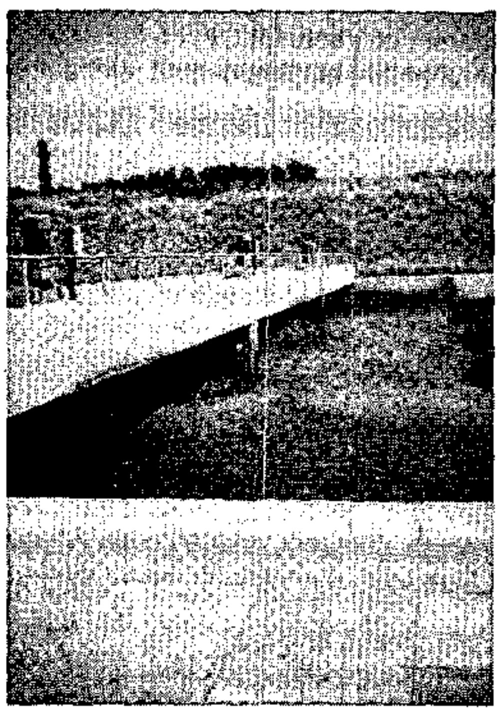


Figure 5a
New frothy scum formed by aerator attaching to harder mass in quiescent area where aerator is switched off

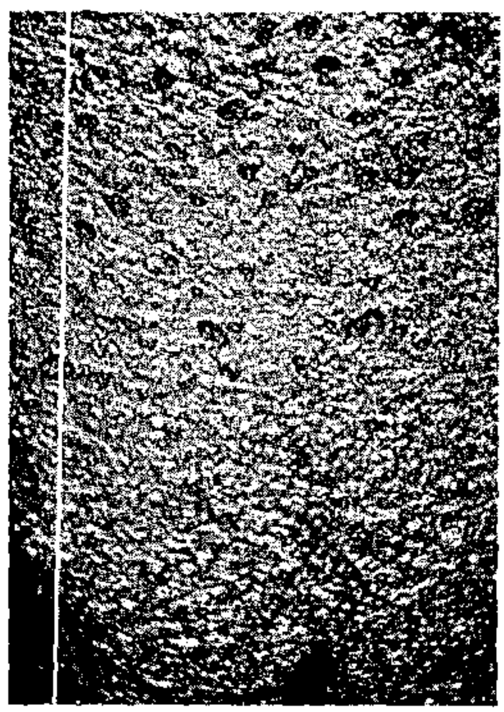
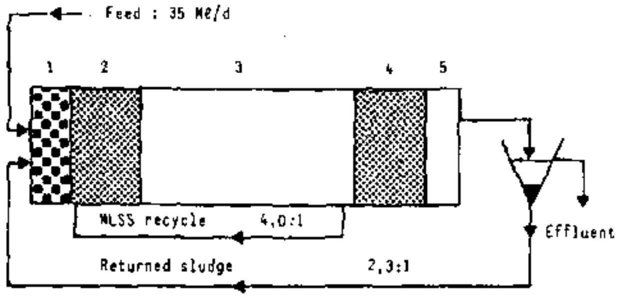


Figure 5c
Large bubbles presenting a very elastic appearance

TABLE 2
PERFORMANCE OF THE NORTHERN WORKS UNDER SCUM FORMING CONDITIONS



Sludge age : 20 days SVI : 170
Temperature : 21 °C Oil SVI : 140
Average DO : 2,6 mg/ℓ

			Primary		Secondary		
Zone	**Feed***	Anaerobic	Anoxic	Aerobic	Anoxic	Aerobic	Effluent*
Total COD	660						47
TKN	52					330*	
Ammonia as N	32	11	4,8	1,6	2,4	1,1	1,2
Nitrate as N		0,3	0,5	3,4	0,9	1,6	1,6
Total P	16					270	
Soluble P	10	14	9,2	1,8		1,4	1,0
Suspended solids						5 000*	19

Where appropriate results expressed as mg/ℓ   * Unfiltered

of the influent sewage also play an important role in the preferential selection of certain filamentous bacteria. A further modification to the influent conditions of one of the modules at the Northern Works is planned for the future and will involve the construction of an anaerobic selector. The effects of scum formation will be observed with interest.

The author has been tempted to speculate on the rôle played by synthetic detergents in bubble stabilisation. Under semi-plug flow conditions the concentration of syndets will obviously be higher at the influent end of the reactor and is more likely to emulsify any bubble stabilisers present, giving rise to a structurally weaker scum. Towards the end of the aerobic zones however, bacteria such as *Acinetobacter*, which are commonly found in nutrient removing plants, may have produced polymers for film stabilisation and at the same time, the available detergents will have been degraded. Under these conditions stable and strong bubble formation could be expected, and is indeed found.

Heavy showers of rain have been found to rapidly break up scum layers and it may well be that floating solids and entrapped air are forced below the surface where detergents have a better opportunity of sequestering the bubble stabiliser and thus contributing to its collapse.

Conclusions

Evidence has been presented to show that air entrainment plays a significant part in the formation of scum on nutrient

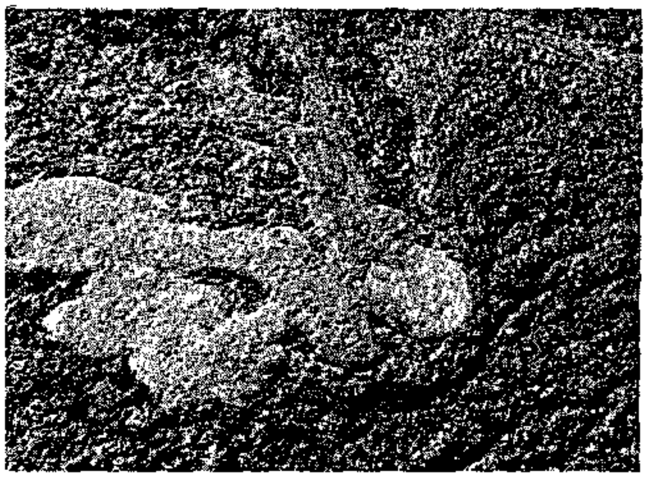


Figure 6a
Light frothy scum surrounded by darker mucoid scum

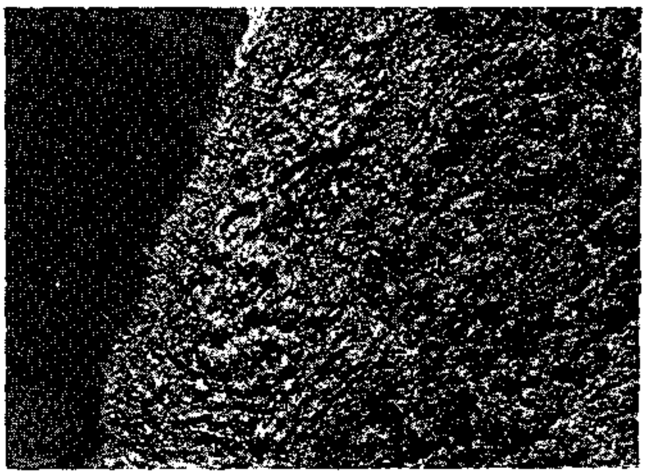


Figure 6b
Illustration of scum build-up. Light frothy scum on left with intermediate section containing large bubbles followed by a dark crusty layer on the right.

Figure 6c
Lower side of picture showing scum being formed in aerobic zone and drifting through the barrier into the anoxic zone

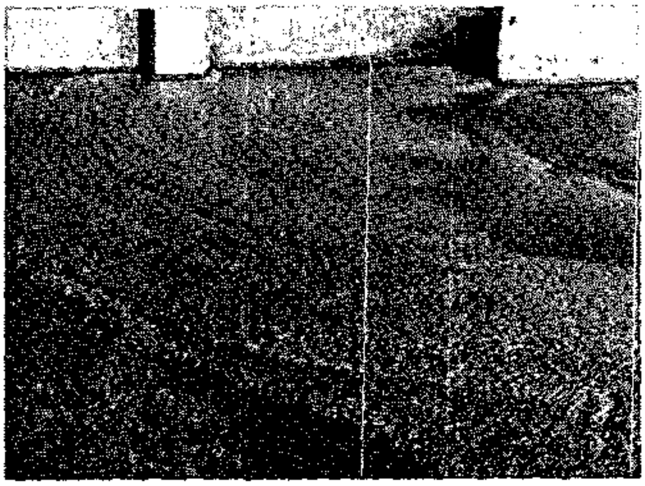


Figure 6d
Anoxic zone side of the barrier showing the semi-circular movement of scum into the anoxic zone where it attaches to the darker scum already present there

Figure 6e
Scum from primary aeration zone being carried into secondary anoxic zone

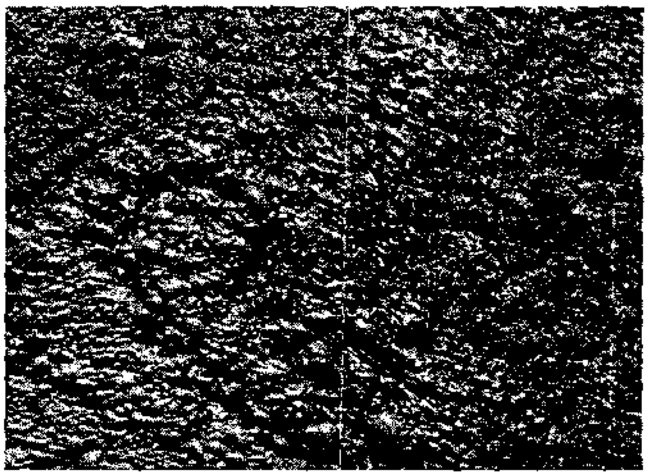


Figure 6f
Elastic appearance of bubbles formed in the sludge return channel

removing activated sludge plants. In existing plants an exit path for scum should be deliberately created to clear stagnant corners and provide a route around baffles. Scum removal may possibly be combined with MLSS wastage for sludge age control and the resultant liquor thickened by air flotation prior to final disposal. Trailing chains hanging in the sludge recycle channel or water sprays across this channel, provide a simple means of breaking up some of the larger bubbles. In the design of new plants air entrainment by cascades, weirs, axial flow pumps, or Archimedian screw pumps should be avoided if possible.

The main disadvantages of scum appears to be aesthetic but may even have distinct advantages when it can provide an air excluding blanket over anaerobic and anoxic zones.

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