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Shredded Newspaper as a Physical Conditioner for Improving Drainability of Brewery Sludge

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Abstract—Sludge dewatering is an essential criterion for the disposal of industrial sludge. Conditioning of the sludge is required for improving the drainability of raw sludge. Physical and chemical conditioners are widely used for this purpose. The suitability of shredded newspaper as a physical conditioner along with inorganic chemical coagulants – alum, ferric chloride, polyaluminum chloride (PAC) and polyacrylamide (PAM) – are studied for conditioning brewery sludge. Among the different combinations, PAC with shredded newspaper is better. The results show that 4 g/L of shredded newspaper with 30 mL/L of 5 % PAC yield a SVI of 37.662 and an efficiency of 39 % in reducing moisture content at the end of 168 hours in sludge drying bed. 4g/L of shredded newspaper alone gives a SVI of 65.254 and efficiency of 36 % in reducing moisture content at the end of 168 hours of drying.

Index Terms— brewery sludge, drainability, physical conditioner, polyaluminum chloride (PAC), shredded newspaper, sludge drying bed, sludge volume index (SVI) .

1 Introduction

Brewing industry produce a variety of waste products which need to be safely disposed. Brewery sludge is bulky in nature and is generally high in moisture. The bulkiness of the sludge must be reduced before disposal. The removal of solid particles in suspension mainly occurs by three mechanisms, namely gravitation, coagulation and flocculation. Gravitational settling is not practical for small size particles. The second process, coagulation, involves destabilization of colloidal suspension by neutralizing the electric forces that keep the suspended particles separated, by adding coagulants. Flocculation is caused by the addition of minute quantities of chemicals known as flocculants. The settleability of raw sludge can be improved using conditioning agents which have a remarkable effect on the dispersed particles. Chemical conditioning agents include inorganic and organic compounds in monomeric and polymeric form, all of which improve the dewatering characteristics of sludge by flocculating the small particles into larger aggregates [15]. Inorganic coagulants have many drawbacks such as high demand for salt, formation of small unstable flocs and a large volume of sludge. The performance of Al & Fe coagulants may worsen with changes in water temperature and the nature of the raw water. In the recent past Polyaluminum chloride (PAC) and Polyacrylamide (PAM) have been used as main polymerized coagulants for industrial sludge treatment due to its higher cationic charge. Small concentrations of these water-soluble polymers can produce large aggregates that can be separated easily. Their flocculation mechanisms as well as the results of the separation process are influenced by the properties of the polymers, such as their charge and molecular weight and of the dispersed material [6]. These polymers do not have a pH dependant action and do not raise the conductivity of the medium, since the load of dissolved ions is less. The pH, at which coagulation occurs, is the most important for proper coagulation performance and it affects the surface charge of colloids, charge of the dissolved-phase coagulant species, surface charge of floc particles, and coagulant solubility.

Chemical conditioners, such as polyacrylamide and inorganic flocculant, improve sludge dewaterability. The combination of ferric chloride and PAM resulted in the production of sludge volume with 60% of the quantity produced, in comparison to ferric chloride alone used [3]. However, achieving final cake solids of a significantly higher solids concentration is hindered by the high compressibility of the flocculated sludge during the compression stage of mechanical dewatering and the sludge cake particles can be easily deformed under pressure following cake growth causing cake void closure and a subsequent reduction in sludge filterability. This can be enhanced by using physical conditioners. Physical conditioners are inert materials and function as skeleton builders because they create a permeable and rigid lattice structure within the sludge, which can remain porous under high pressure filtration, to allow water to be forced out under pressure [15]. A wide range of carbon-based materials have been used as physical conditioners, including lignite, char, coal fines; organic waste solids such as bagasse, wood chips and wheat dregs; minerals including gypsum fly ash from municipal sludge incineration, coal fly ash modified by sulfuric acid, cement kiln dust, etc.

Dewaterability of a sludge sample measures the efficiency of a flocculent in aiding settling. The drainability is measured by the concentration of solids left after dewatering the sample. Several methods of dewatering have been tried by researchers. These include vaccum filters, filter presses, centrifuges, drying beds and sludge lagoons, to name a few. Out of these, sludge drying beds are reported to have a solids recovery of 90-100 % and can

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be operated at a low cost without skilled labour and is hence adopted in the present study. They are used to dewater sludge both by draining through the sludge mass and by evaporation from the surface exposed to the air. Dewatering on sand beds proceeds via. two different mechanisms: filtration and evaporation. Water drainage is most important during the first 1–3 days leaving solid concentrations as high as 15–25%. Further water removal occurs by evaporation. Horizontal shrinking of the sludge and exposure of additional sludge areas facilitate evaporation. Nearly 60% of the water is estimated to be drainable. Up to 85% of the water of secondary sludges can be lost by drainage. In general, the higher the initial water content, the larger is the fraction of drainable water. Drainage time and cake moisture increase with increasing depth of the charge. The drying rate can be increased by sludge conditioning with organic or inorganic coagulants-flocculants. Chemical conditioners permit higher sludge porosity, decrease solids compression, and result in reduced sand bed maintenance. The jar test and settling column study, combined with drainability analysis gives a clear idea about the efficiency of different conditioning agents. Considering the promising results of studies on interaction of polymeric coagulants with cellulose fibres, paper can be proposed as a physical agent in conditioning of industrial sludge. Here the focus is on studies conducted on the effect of paper in settling, both individually and in combination with chemical coagulants.

2 MATERIALS AND METHODS

2.1 Sampling Techniques and Preservation

The sludge from the brew-house of United Breweries Ltd., Kanjikode, Kerala, was collected using the composite sampling technique. The sludge was collected at two hours interval everyday for six days between the hours of 8.00 a.m. and 6.00 p.m. from the equialization tank receiving primary and secondary sludge. Each time, one liter of the sludge was collected from the source and transferred into a 20 liter container and kept in the refrigerator. This was done repeatedly for six days. Refrigeration was done to prevent the growth and multiplication of microorganisms and to inhibit their actions on the sludge. Where analysis could not be carried out, samples were preserved as per standard methods

2.2 Methods of Analysis (Physicochemical Characteristics of the Sludge Sample)

Sludge samples were analyzed as described in the *Standard Methods for the Examination of Water and Wastewater* (APHA). Inorder to study the settling characteristics, jar test was performed for various coagulants namely Alum, Ferric chloride, Polyacrylamide, and Polyaluminium Chloride at varying dosages, by keeping pH at the optimum. Suitability of paper as a physical conditioner at their respective pH was also studied using jar test. Shredded newspaper of size 15 mm x 2 mm was used for the study. After adding coagulant, flash mixing was done for 1 minute at 100 rpm, followed by flocculation at 30 rpm for 20 minutes. Then, paper was added and stirred for 1 minute at 20 rpm. The sludge is then transferred to 1 L measuring jar for settling study.

Sludge Volume Index was determined as follows.

$$SVI = \frac{\text{30 min. settled sludge volume (mL/L)}}{\text{Suspended solids concentration (mg/L)}} \times 1000$$

After getting the optimum dosage, sludge mixed with this optimum dosage was discharged on 6 drying beds, each with 8 L of sludge of different combination of coagulants. The drying bed was designed as 2 rectangular boxes of size 40cm x 60cm x 30cm, with 3 units in each (Fig 1, 2). At the bottom, drainage outlet was provided to collect the filtrate. The underdrainage system involved a common outlet pipe of 2 inch diameter, at the centre of the bed. The bottom most layer was of 5 cm thick gravel passing through 4.75 mm sieve and retained on 2.36 mm sieve. It was overlaid by finer gravel of size between 2.36 mm and 1.18 mm, 5 cm thick. The 10 cm thick gravel base supported sand on its top, filled in three layers, together making a height of 5 cm, with the coarser type of effective size 1 mm at bottom, 2 cm thick, overlaid by 2 cm thick layer of finer sand of effective size 0.6 mm, supporting 1 cm thick top layer of sand of effective size 0.3 mm. Tests were done using the four chemical coagulants namely, alum, ferric chloride, PAC, and PAM, and physical conditioner – shredded newspaper – each individually at their optimum dosages as obtained from the settling study. The chemical coagulants in combination with optimum dosage of paper, was also studied. The sludge was spread uniformly on the top of the sand layer to a thickness of 10 cm. After a draining period of 2 days, the bed was kept in open atmosphere for 3 days. The drainability and drying was studied by determining the moisture content variation in the beds with time. For this, samples were taken from the four corners, centre and edges.

Table 1: Characteristics of coagulants

Type	$FeCl_3$	Alum	PAC	PAM
Colour	White	White	Golden brown	Off-white
Effective pH	3.5-6.5 & > 8.5	6-8.5	4.5-10	2-7.5
Solubility	Soluble	Soluble	Soluble	Soluble
Suitability	Waste water	Relatively clear water	Drinking water and waste water	Suspensions

3 RESULTS AND DISCUSSION

The physical and chemical characteristics of sludge are presented in Table 2. For settling study, the total suspended solids concentration and the 30 minutes settled sludge volume was determined and the sludge volume index was calculated as per *Standard Methods*. The results are plotted on graphs in Fig 7 to Fig 10. The results reveal that, for all the chemical condi-

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tioners and paper, the sludge volume index reduces upto an optimum dosage, and then increases.

Fig 1 Top view of drying bed with gravel & sand at filling stage

Fig 2: Drying bed with sludge

Fig 3: Sampling for moisture content analysis

Table 2: Results of the brewery sludge characterisation study

Parameter	pH	Conductivity (µS)	Moisture Content (%)	Total solids (mg/L)	Alkalinity (mg/L)	Turbidity (NTU)	BOD(mg/L)	COD (mg/L)	Iron (mg/L)	Hardness (mg/L)	Chloride (mg/L)
Values	8	4130	97.07	14700	900	5820	1770	4096	220	60	730
	7.2	6840	97.97	10180	1733	7400	2490	6080	180	60	850
	9.3	5200	98.13	9450	1940	6820	2730	6480	190	80	750
	8.5	6400	95.44	22860	1500	8010	2350	5460	175	75	840
	9	6620	96.48	17690	1820	7240	2970	6750	180	70	870
	7.8	4800	95.32	23450	1710	6620	2060	4580	210	80	760
Mean	8.1	5665	96.73	16388	1601	6985	2395	5574	193	71	800
Std. Dev	-	1109	1.11	5522	340	684	399	970	17	8	55

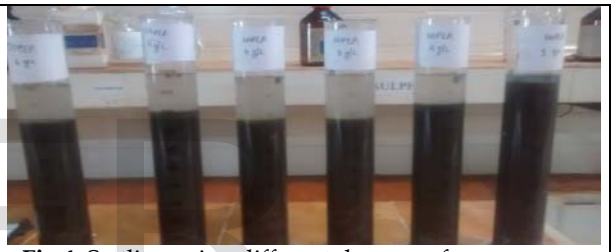

Fig 4: Settling using different dosages of paper

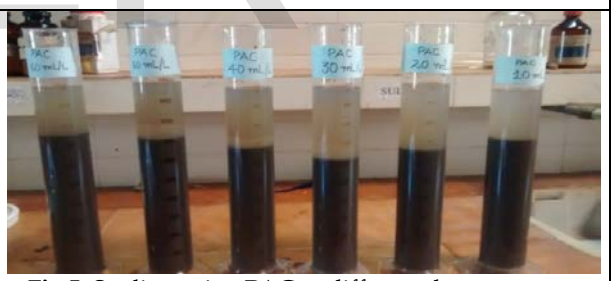

Fig 5: Settling using PAC at different dosages

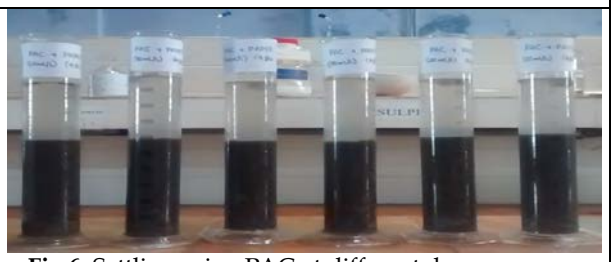

Fig 6: Settling using PAC at different dosages with 4 g/L paper

With addition of an optimum dosage of paper (4g/L), the settling was significantly enhanced. The sludge volume index was minimum for a combination of 30 mL/L of 5% PAC and 4g/L paper.

Further, the settling column study done to analyse the trend of settling revealed that the settling rate was high in the beginning upto 30 minutes and then reduced till the settling attained an almost constant value (Fig.10). Visual observation

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revealed that addition of paper causes particles to form large flocs and they settle as a unit, similar to compression settling.

Table 3: Sludge Volume Index (SVI) using different dosages of different settling agents

Settling agent	Parameter	Observed values at different dosages of different settling agents					
Paper	Dosage g/L	1	2	3	4	5	6
	SSV mL/L	950	780	780	770	800	850
	TSS mg/L	11800	11800	11800	11800	11800	11800
	SVI	80.50	66.10	66.10	65.25	67.8	72.03
$FeCl_3$	Dosage g/L	1.5	3	4.5	6	7.5	9
	SSV mL/L	880	870	820	820	870	890
	TSS mg/L	12800	12800	12800	12800	12800	12800
	SVI	68.75	67.97	64.06	64.06	67.97	69.53
$FeCl_3$ + 4 g/L paper	Dosage g/L	1.5	3	4.5	6	7.5	9
	SSV mL/L	850	760	690	700	720	750
	TSS mg/L	12800	12800	12800	12800	12800	12800
	SVI	66.41	59.38	53.91	54.69	56.25	58.59
Alum	Dosage g/L	1	1.5	2	2.5	3	3.5
	SSV mL/L	940	870	880	900	910	920
	TSS mg/L	10950	10950	10950	10950	10950	10950
	SVI	85.84	79.45	80.37	82.19	83.11	84.02
Alum + 4 g/L paper	Dosage g/L	1	1.5	2	2.5	3	3.5
	SSV mL/L	950	800	740	750	770	780
	TSS mg/L	10950	10950	10950	10950	10950	10950
	SVI	86.76	73.06	67.58	68.49	70.32	71.23
PAC (5%)	Dosage mL/L	10	20	30	40	50	60
	SSV mL/L	740	680	640	700	720	760
	TSS mg/L	15400	15400	15400	15400	15400	15400
	SVI	48.05	44.16	41.56	45.45	46.75	49.35
PAC (5%) + 4 g/L paper	Dosage mL/L	10	20	30	40	50	60
	SSV mL/L	660	620	580	590	600	610
	TSS mg/L	15400	15400	15400	15400	15400	15400
	SVI	42.86	40.26	37.66	38.31	38.96	39.61
PAM	Dosage g/L	1	1.5	2	2.5	3	3.5
	SSV mL/L	860	840	770	800	840	870
	TSS mg/L	12600	12600	12600	12600	12600	12600
	SVI	68.25	66.67	61.11	63.49	66.67	69.05
PAM + 4 g/L paper	Dosage g/L	1	1.5	2	2.5	3	3.5
	SSV mL/L	800	710	670	680	690	700
	TSS mg/L	12600	12600	12600	12600	12600	12600
	SVI	63.49	56.35	53.17	53.97	54.76	55.56

Notes: *1. Abbreviations: SSV: Suspended solids Settled Volume; TSS: Total Suspended Solids; SVI: Sludge Volume Index*
2. pH of the sample was adjusted to 7.5 for PAM, 8.5 for $FeCl_3$ and 8 for all the remaining combinations

Table 4: Comparison of effect of coagulants /conditioner in settleability enhancement

Coagulant/Conditioner	pH	Optimum dosage	Minimum SVI
Paper	8	4 g/L	65.254
Alum	8	1.5 g/	79.75
$FeCl_3$	8	4.5 g/L	64.063
PAC	8	30 mL/L	41.558
PAM	7.5	2 g/L	61.111
Alum with 4g/L paper	8	2 g/L	67.58
$FeCl_3$ with 4g/L paper	8	4.5 g/L	53.906
PAC with 4g/l paper	8	30 mL/L	37.662
PAM with 4g/L paper	7.5	2 g/L	53.175

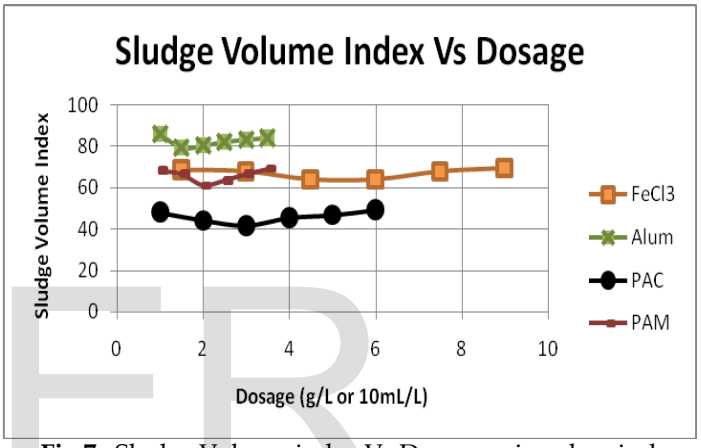

Fig 7: Sludge Volume index Vs Dosage using chemical Coagulants

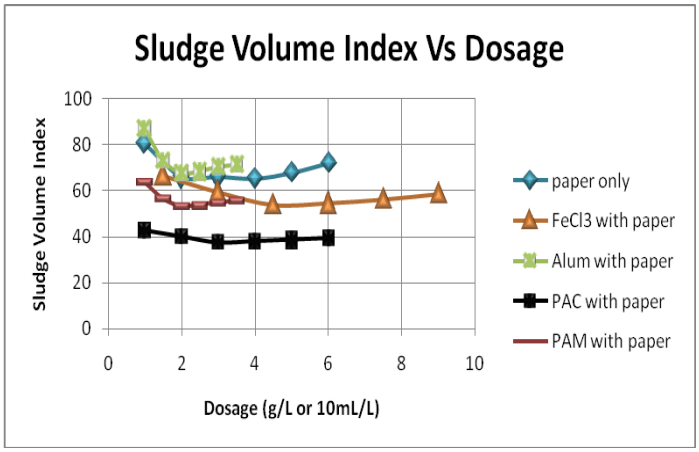

Fig 8: Sludge Volume Index Vs dosage with paper

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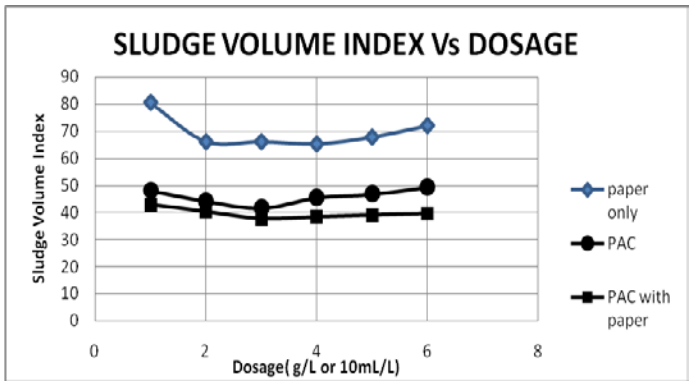

Fig 9: Sludge Volume Index Vs Dosage for PAC and paper

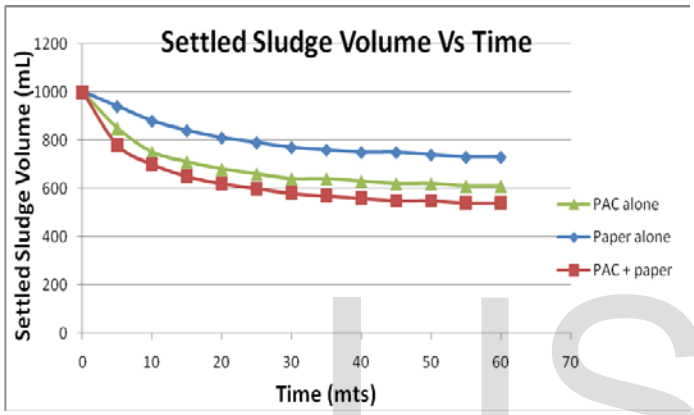

Fig 10: Variation of settled sludge volume with time for PAC and Paper

Table 5: %Moisture content with time for various coagulants

Coagulant	% Moisture content at various times (hrs)										
	0	12	24	36	48	60	72	96	120	144	168
A	95	86	81	77	75	73	71	69	67	65	64
FC	96	86	82	77	76	73	71	70	67	65	65
PAC	97	87	82	78	74	71	70	67	66	65	62
PAM	96	86	82	77	74	71	69	67	65	64	62
P	96	86	81	77	74	71	69	67	65	63	62
A + P	98	87	83	79	77	75	74	71	68	68	66
FC+P	98	88	83	79	77	75	74	71	69	66	66
PAC+P	97	87	80	76	72	69	66	64	62	61	60
PAM+P	98	87	82	77	75	71	69	68	65	64	62

Abbreviatios: A-Alum, FC-$FeCl_3$, P-Paper

Table 6: Efficiency of coagulants /conditioner (optimum condition) in reducing moisture content with time

Coagulant	*Efficiency in reducing moisture content at various times (hrs)*										
	0	*12*	*24*	*36*	*48*	*60*	*72*	*96*	*120*	*144*	*168*
Alum	0	10	15	20	21	24	26	27	30	32	33
$FeCl_3$	0	10	15	19	21	24	25	27	30	32	32
PAC	0	11	16	20	24	27	28	31	32	33	36
PAM	0	11	15	20	23	26	28	31	33	34	35
Paper	0	11	15	20	23	26	28	31	33	34	36
Alum + paper	0	11	15	20	22	24	25	28	30	33	33
$FeCl_3$ + paper	0	10	15	20	22	24	25	28	30	33	33
PAC + paper	0	10	18	22	26	29	32	34	36	37	39
PAM + paper	0	11	16	21	23	27	29	30	33	35	36

From the drainability study on drying beds, it is observed that within twelve hours of draining, the moisture removal efficiency is 10-11%. In 2 days, it is increased to 15-18%, which is further enhanced to nearly 30-36% within 5 days, with the highest being for PAC-paper combination (39%) followed by PAM-paper Combination (36%) at the end of 7 days. At the same time, it is observed that paper alone achieved a nearly equal efficiency of 36% in 7 days.

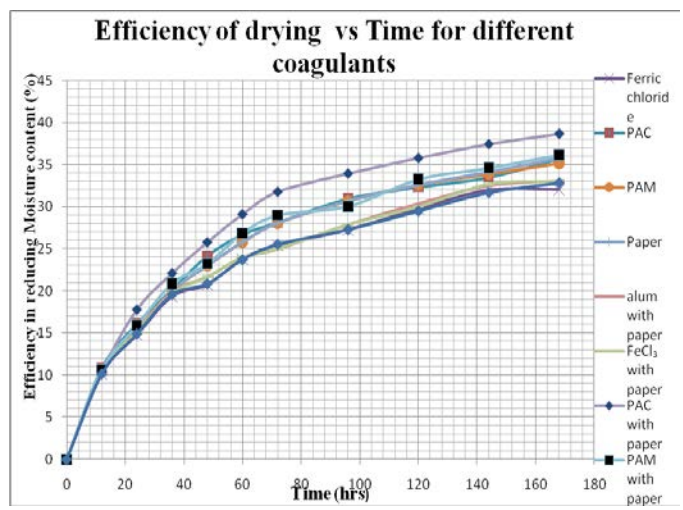

Fig 11: Plot showing efficiency of various coagulants in reducing moisture content with time

4 CONCLUSION

From the settling column study and drainability analysis, it can be concluded that paper enhances the effect of polyelectrolytes and chemical conditioning agents in settling and is found to be optimum at a concentration of 4g/L. From the drainability study, it is clear that sludge drying beds reduce the moisture content of brewery sludge to nearly 60% within five days of operation. Most effective drying occurs on addition of Polyaluminium Chloride in combination with optimum dosage of paper; but the enhancement in efficiency due to addition of PAC is negligible, since paper alone achieves nearly equal reduction in moisture content in the same time gap. Paper is also effective in enhancing the settleability of the sludge, without addition of chemical coagulants. Thus, the study shows that paper enhances the effect of chemical coagulants in improving the settleability and drainability properties of brewery sludge. Moreover, paper alone, also performs well in enhancing the settling and drainability of sludge, and can hence be adopted as a suitable physical agent in settling and drying of brewery sludge, thus reducing the dependency on chemicals. Paper is also used as a bulking agent in composting, to increase the porosity. Newspaper is low-cost, easily available and degradable. Therefore sludge conditioned with newspaper can be used for composting.

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