Disposal and Purification

of

Factory Wastes or Manufacturing Sewage.

BY

H. W. CLARK,

Chemist to the Massachusetts State Board of Health.

Reprinted from the Forty-first Annual Report of the Massachusetts State Board of Health.

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The disposal and purification of manufactural wastes has been the subject of much investigation by the State Board of Health of Massachusetts during the past fifteen years, both at the Lawrence Experiment Station and at certain industrial establishments in the State. The nature of these wastes has been varied, including those from tanneries, woolen factories, paper mills, dye works, creameries, binders' board works, yeast factories, carpet works, batting works, silk mills, gas works, bleacheries, shoddy mills, glue works, paint mills, etc. As a result of these investigations practical and satisfactory methods for the disposal of many of these wastes have been developed, and at the present time a number of purification plants are in operation or under construction in Massachusetts. The subject is a broad one, and many difficulties have been encountered that are absent from the problem involved in the disposal of domestic sewage, and which, oftentimes, prevent a general application of the results obtained. The chief difficulties are (1) the nature of the waste liquor in some manufacturing processes whereby purification by bacterial action or nitrification is prevented; (2) the excessive amount of solid matter per unit volume of liquor, especially carbonaceous matter, — often many times as great as that found in the strongest domestic sewage; (3) the enormous volume of liquor used in many industries, which liquor comes from such plants loaded with organic matter and chemicals of many kinds; (4) the varying character of the liquor coming from different manufacturing plants doing similar work, — a fact which prevents the experimental data from being universally applicable; and (5) the liability to change, from time to time, in the processes carried on in any industrial plant.

Wastes from Tanneries.[1]

Tannery A.

During the past fourteen years the wastes from three tanneries have been experimented upon. The first tannery investigated was engaged in preparing and tanning sheep skins. The daily volume of the waste varied from 20,000 to 50,000 gallons, and was composed of a thick, offensive liquor varying in color as different aniline dyes were used. The amount of organic matter present was large and in an advanced state of putrefaction. It seldom contained any substance of a character to check bacterial action and was, therefore, easily nitrified. The sludge was at times great in volume and rich in fats and nitrogenous matters. A filter was constructed at this tannery, containing 2 feet in depth of sand of an effective size of 0.14 millimeter, over gravel underdrains; and sewage, made up of a mixture of the waste liquors from all the processes carried on at the tannery, was first applied to it on Sept. 27, 1895, at an average rate of 55,000 gallons per acre daily. During a large part of its period of operation, however, the rate was 25,000 gallons per acre daily, but even at this rate the filter became clogged quickly by matter in suspension in the waste.

The following analyses show the character of the liquor as applied to and of the effluent from this filter during its period of operation: —

Average Analysis of Liquor applied to Filter.

[Parts per 100,000.]

Ammonia.			Kjeldahl Nitrogen.	Chlorine.	Nitrogen as —		Oxygen Consumed.
Free.	Albuminoid.						
	Total.	In Solution.			Nitrates.	Nitrites.	
3.74	3.16	1.91	5.92	387.20	.16	.0015	61.25

Average Analysis of Effluent from Filter.

Free	Total	In Solution	Kjeldahl Nitrogen	Chlorine	Nitrates	Nitrites	Oxygen Consumed
2.65	0.48	0.20	0.69	284.25	.60	.0068	7.92

It was evident that better nitrification and higher rates of filtration could be obtained if suspended matter was removed from the sewage before filtration.

[1] In some instances, the filters as described in the various annual reports in connection with the purification of manufactural wastes, bear different numbers than in this review. The numbers given here are for the sake of clearness and to prevent confusion.

Precipitation with Lime. — In one of the processes at the tannery a large amount of lime was used, and milk of lime was being mixed almost continuously with the rest of the waste. Experiments soon showed that 60 per cent. of the organic matter could be removed by sedimentation with the aid of this lime waste. The resulting supernatant liquor, still very rich in organic matter in solution, was first applied in January, 1896, to a filter $\frac{1}{20000}$ of an acre in area and containing 4 feet in depth of sand of an effective size of 0.14 millimeter. This filter was located in a building in which the temperature was but slightly above the freezing point during the winter, and, because of this low temperature, nitrification did not become active until the approach of warm weather. The waste was applied for four months at the rate of 120,000 gallons per acre daily, but this rate was found to be excessive for so strong a sewage, and was reduced to 60,000 and then to 30,000 gallons per acre daily. Nitrification began in May, 1896, and the filter was continued in operation until September, 1898. Nitrification continued active; the effluent from the filter was clear and colorless, and when the filter was discontinued it was working satisfactorily, and gave promise of doing so indefinitely.

The following table gives the average analysis of the liquor applied to and of the effluent from this filter: —

Average Analysis of Tannery Sewage applied to Filter.

[Parts per 100,000.]

Ammonia.			Chlorine.	Nitrogen as —		Oxygen Consumed.	Fats.
Free.	Albuminoid. Total.	Albuminoid. In Solution.		Nitrates.	Nitrites.		
6.82	2.39	1.83	375	0.17	.0112	46.66	8.97

Average Analysis of Effluent from Filter.

1.45	0.23	0.12	405	9.96	.0258	1.79	6.00

A third filter, constructed of 4 feet in depth of sand and receiving a mixture of the tannery liquor and domestic sewage, was kept in operation from June, 1896, until the beginning of 1898. During most of this period the mixture had the proportions of 1 part tannery liquor to 2 parts sewage, and was applied to the filter at rates between 40,000 and 50,000 gallons per acre daily, with satisfactory purification.

Coke Strainer. — A coke strainer, containing 2 feet in depth of coke, the upper portion being coke breeze and the lower portion coarser coke, was started at the tannery in December, 1896, and continued in operation until October, 1898. Operating at rates varying from 250,000 to 300,000 gallons per acre daily, it was successful in removing about 85 per cent. of the crude organic matters in the applied sewage, represented by the determinations of albuminoid ammonia, and 83 per cent. of those represented by the determinations of oxygen consumed. The effluent from the strainer even after the removal of this large amount of organic matter was fully as strong as ordinary city sewage, but could be purified easily at a high rate upon ordinary sand filters. Some nitrification occurred in the strainer, and its effluent was often fairly clear and of a color easily read upon the color standards used at Lawrence, while the applied sewage was always highly colored, either black, red or brown, according to the nature of the work being carried on in the tannery. Sludge was removed from the surface of the strainer several times. This sludge could be disposed of readily on a large scale by burning under boilers, especially as it contained considerable fat in addition to the coke which was removed with the deposit on the filter.

The average analysis of the tannery sewage applied to and of the effluent from the coke strainer follow: —

Average Analysis of Liquor applied to Coke Strainer.

[Parts per 100,000.]

Ammonia.			Nitrogen as —		Oxygen Consumed.	Fats.
Free.	Albuminoid.					
	Total.	In Solution.	Nitrates.	Nitrites.		
4.04	4.45	2.54	-	-	95.20	22.70
Average Analysis of Effluent from Coke Strainer.						
1.90	0.35	0.20	.56	.0151	3.96	3.07

The investigations made with the wastes from this tannery are described in the report of the Board for 1895, pp. 471 and 472; report for 1896, pp. 433–438, inclusive; report for 1897, pp. 397 and 398; report for 1898, pp. 463–465, inclusive.

Tannery B.

Experiments upon the filtration of wastes from a tannery engaged in preparing and tanning calf skins were made during 1896 and 1897. The volume of liquor flowing from the tannery exceeded 200,000 gallons per day. It was a thick, offensive liquor containing a very large amount of organic matter, and was generally colored by dyestuffs. Some of the skins were imported, and came packed in a germicide to prevent decomposition; and this germicide, largely naphthalene, was present in the sewage throughout the period of examination. The waste liquor also always contained arsenic both in suspension and in solution, inasmuch as a ton or more of sulphide of arsenic was mixed with the lime each month to help free the skins of hair. A large amount of the organic matter was present in suspension, and experiments showed that it would settle out from the main body of sewage very completely in one hour, with the aid of the lime and other chemicals present. A considerable portion of the arsenic was held by the organic matter in suspension and was carried down with it, but the supernatant sewage after sedimentation contained generally enough arsenic to check bacterial growth. This supernatant sewage was applied to a sand filter and a coke strainer at average rates of 50,000 and 100,000 gallons per acre daily, respectively, and the effluent from the coke strainer was applied to another sand filter at the latter rate.

The first filter (No. 71), containing 4.5 feet in depth of sand, produced a satisfactory effluent generally, but nitrification ceased entirely when the applied sewage contained more arsenic than usual. Operated at a rate of 100,000 gallons per acre daily, the coke strainer (No. 72), containing 2 feet in depth of coke breeze, had its surface covered for about two hours daily. It removed considerable organic matter and generally all the arsenic from the sewage. When the sewage applied to this coke strainer contained so much arsenic that only a few hundred bacteria were found growing in it, its effluent contained several million bacteria per cubic centimeter. The second sand filter (No. 73), constructed of 4.5 feet in depth of sand and receiving the effluent from the coke strainer at a rate of 100,000 gallons per acre daily, maintained uniformly good nitrification and purification.

The following table gives the average analysis of the sewage applied to and of the effluent from each of these three filters: —

[Parts per 100,000.]

	Ammonia.		Chlorine.	Nitrogen as —		Oxygen Consumed.	Bacteria per Cubic Centimeter.
	Free.	Albuminoid.		Nitrates.	Nitrites.		
Sewage applied,	1.09	4.70	43.00	0.00	.0000	40.50	–
Effluent from Filter No. 71,	2.36	0.61	44.96	0.74	.0313	10.12	589,260
Effluent from Filter No. 72,	2.76	0.77	39.81	0.12	.0249	10.57	437,000
Effluent from Filter No. 73,	0.42	0.11	43.41	1.97	.0167	3.52	87,600

Removal of Arsenic by Coke and Iron. — Methods for removing the arsenic from this tannery sewage were studied, and it was found, as stated previously, that by passing the sewage through a filter or strainer of coke breeze it was quite thoroughly freed from arsenic. This removal was due probably to the presence of iron in the coke, since the same result was accomplished by passing the sewage through iron filings or turnings.

Average Amount of Arsenic (As_2O_3) in Entire and Supernatant Sewage, and Effluent from Coke Strainer.

[Parts per 100,000.]

Entire tannery sewage,	8.5447
Supernatant tannery sewage,	1.6757
Effluent from coke strainer,	0.0823

Generally speaking, the effluent from the coke strainer was free from arsenic, but occasionally, if an excessive amount was applied and if the strainer was overworked, some arsenic would pass through. Examination of the coke proved that a large percentage of the arsenic was retained in the upper few inches of the strainer. For example, a small strainer containing 2 feet in depth of coke breeze was flooded each day for two weeks with this sewage. The effluent examined each day was found to be free from arsenic. On October 15 the coke itself was examined, with the following results: —

Arsenic as As_2O_3.

[Parts per 100,000.]

Upper 4 inches of coke,	36.40
Middle 4 inches of coke,	6.60
Lower 4 inches of coke,	0.20

The investigations upon the wastes from this tannery are fully described in the report of the Board for 1896, pp. 431–433; and in the report for 1897, pp. 396 and 397.

Tannery C.

In 1900 an application was received by the Board from a tannery, asking advice as regards the improvement of its wastes and stating that for years a system of settling basins had been maintained at considerable expense. The following conditions were found to obtain at this tannery: the chief waste liquors were those from the processes of wool-scouring, skin-washing, tanning, dyeing and the drainage from the water-closets used by about 300 employees, all of these wastes passing to the settling basins. The water used in the last bowl of the wool-scouring machine was discharged into a stream in wet weather, but when the flow was small this water was used for skin-washing. The wool after being scoured was rinsed in rinsing machines, which used a great quantity of water, — about 500,000 gallons per day. The most objectionable waste was the drainage from the glue-stock washer. This was a cylindrical tank 17 feet in diameter, located in the floor of the skin-washing room, but at so low an elevation that it could not be connected with the main drain leading to the settling basins. The waste from the process of glue-stock washing amounted to about 22,000 gallons a day, and contained lime and dirt from the skins, and, on alternate days, sulphuric acid. Measurements of the flow of sewage and also of the water flowing out of the settling basins were made, the amounts of the latter being on four different days, — namely, October 8, November 12, November 22 and November 25, — 322,000, 400,000, 370,-000 and 350,000 gallons, respectively.

Two small sand filters, each containing 5 feet in depth of sand of an effective size of 0.24 millimeter, were put into operation. The waste liquor resulting from the preparation of hides for tanning was applied to Filter No. 1, and to Filter No. 2 the waste liquor from certain processes necessary in tanning hides, together with considerable wool-scouring liquor. Both filters were continued in operation for three months at a rate of 63,000 gallons per acre daily, producing well-purified effluents with but little odor, the results thus showing that the sewage from both drains at the tannery could be purified easily upon sand filters. Following this, the sewage from both drains was applied to Filter No. 1 at an average rate of 83,500 gallons per acre daily for two months. By mixing these sewages and applying both to one filter the effluent was caused to be considerably higher in color, and nitrification became more active after the application of the mixed sewage than before.

From 1901 to 1904 the waste from this tannery increased materially, 434,000 gallons being the daily volume at the time measurements were made during the latter year. The quantity of wet sludge removed by the crude settling tanks at the tannery in 1901 was estimated to be about 3,700 cubic feet, and better settling basins would probably have removed a larger quantity.

Experiments made at Lawrence in 1904 indicated, in confirmation of earlier experiments with this waste, that it might be practicable to purify this tannery sewage upon sand filters operated at a rate as great as 80,000 gallons per acre daily.

In September, 1907, further investigations of the wastes from this tannery were carried on at the experiment station, and filters were again put into operation, to which were applied the wastes from the outlets of the settling tanks. The process of tanning at the works at this time was found to be about as follows: the hides were first steamed and soaked in order to make them soft, then the inside of the skin was painted over its entire surface with a decoction containing arsenic. The skins were then folded with the painted surface inside and allowed to remain over night in a warm atmosphere and "sweated." The arsenic so affected the hide that the hair could be easily removed. The skins were then washed. The waste water contained practically all the arsenic, but this was mixed with the entire volume of waste liquors which flowed from the tannery. It was suspected that the arsenic in the waste liquors might prevent nitrification and therefore good purification by filtration.

A filter (No. 332), containing 4 feet in depth of sand of an effective size of 0.25 millimeter, was put into operation at a rate of 75,000 gallons per acre daily. The waste as received at the station was applied until November, when the effluent of the contact filter (No. 334), constructed of 2 feet in depth of coke breeze and iron turnings (1 part of iron to 9 parts of coke), was applied to it. This filter was operated with the waste as received at a rate of 250,000 gallons per acre daily, two hours' contact being allowed. Nitrification did not occur to any great extent in the sand filter until the effluent of the contact filter was applied. The beginning of nitrification at this time was probably a coincidence, however, as other experiments seemed to show that nitrification would have started without the preliminary treatment in the contact filter. Nitrites, furthermore, had been very high in the effluent of the sand filter at times previous to the application of the effluent of the contact filter. The amount of arsenic in the waste liquors was not large, the average in many samples examined being only 0.13 part per 100,000, and of this, the contact filter removed practically 54 per cent.

Another filter (No. 333) was started in November, 1907, of the same size and depth of sand as the filter just mentioned. It was operated at a rate of 75,000 gallons per acre daily at first and then at 100,000 gallons per acre daily, the dose applied to this filter being equal parts of Lawrence sewage and tannery waste. Nitrification was active until the rate was changed, when it became much poorer. In addition to these filters, a sand filter (No. 335) was operated with Lawrence sewage to which arsenic was added. The sewage at first contained 0.01 of a part of arsenic and the amount was increased each week until the arsenic applied equaled 50 parts per 100,000. The effluent from the filter contained about 6 per cent. of the arsenic in the applied sewage. The following February the sand from the surface of the filter contained 1.2 parts arsenic per 100,000, and sand at a depth of 6 inches, 0.6 part arsenic.

The following table gives the average analysis of the effluent from each of these four filters: —

Average Analysis of Effluent from Filter No. 332.

[Parts per 100,000.]

Color.	Ammonia.		Nitrogen as —		Oxygen Con-sumed.	Arsenic.	Hardness.
	Free.	Albumi-noid.	Nitrates.	Nitrites.			
.17	2.2524	.0735	2.31	.5722	.51	.03	18.5

Average Analysis of Effluent from Filter No. 333.

.11	3.6720	.0760	0.96	.0778	.45	.01	15.0

Average Analysis of Effluent from Filter No. 334.

-	2.5781	1.5631	0.08	.0478	8.58	.06	24.7

Average Analysis of Effluent from Filter No. 335.

[Parts per 100,000.]

Color.	Ammonia.		Chlorine.	Nitrogen as —		Oxygen Con-sumed.	Arsenic.		Hard-ness.
	Free.	Albumi-noid.		Nitrates.	Nitrites.		Applied.	Effluent.	
.10	.2841	.0371	11.30	5.59	.0014	.26	.33	.02	—0.2

From the above experiments it seemed probable that good sand filters receiving the sewage from the outlet of the settling tanks at the tannery would, if operated at reasonable rates, produce good nitrification even with considerable arsenic in this waste, but that some arsenic would accumulate in the upper layers of the sand; that it would be best to pass the sewage, after sedimentation, through filters of coke breeze for partial purification and for the removal of a considerable percentage of arsenic before passing the sewage to sand filters.

During 1909 filters were again operated with waste from this tannery. The first filter, containing 3½ feet in depth of sand, was operated at rates varying from 50,000 to 150,000 gallons per acre daily, producing an effluent which was odorless and but slightly turbid.

A Trickling Filter receiving Tannery Sewage. — A second filter, containing 6 feet in depth of broken stone, was started in May, 1909, and was operated at rates varying from 500,000 to 1,500,000 gallons per acre daily, and a well-nitrified, stable and practically odorless effluent resulted. The supernatant liquor after a short period of standing was clear, and the sediment was as stable as the characteristic sediment of all good trickling filters. The average analysis of the effluent from this filter was as follows: —

[Parts per 100,000.]

Color.	Ammonia.		Nitrogen as —		Oxygen Consumed.
	Free.	Albuminoid.	Nitrates.	Nitrites.	
1.18	1.48	.39	2.54	.085	4.27

In June the effluent from this filter was applied to a sand filter 3½ feet in depth and operated at a rate of 150,000 gallons per acre daily. This latter filter produced an effluent with the following average analysis: —

[Parts per 100,000.]

Color.	Ammonia.		Nitrogen as —		Oxygen Consumed.
	Free.	Albuminoid.	Nitrates.	Nitrites.	
0.61	0.48	.10	3.60	.029	0.92

All these filters were kept in operation without difficulty and were in good condition at the end of the experiment. The matter in suspension separated more easily in warm weather than during the colder portion of the year, but during the entire period of operation the filters did not cease to give good nitrification.

Waste Liquors from Scouring and Washing Wool.

The liquor resulting from scouring and washing wool by the old-fashioned methods, which are still quite common in Massachusetts mills, is large in volume and exceedingly rich in mineral and organic matters, both in solution and suspension, and of a nature not readily acted upon by the bacterial agencies of putrefaction, decomposition and nitrification. Since 1895 studies have been made by the Board of the wastes from a number of large plants where this work is carried on. Many measurements of the volume of water used per gallon of wool scoured and washed have been made, and also many estimates of the amount of dirt contained in these liquors. Some of these measurements follow. The differences are due either to the varying quality of wool washed or to variations in the manner of operation, depending upon the degree of cleanliness required of the wool.

Plant No. 1. — Sixty-seven thousand gallons of water per day used per 42,000 pounds of wool scoured; 2,144 pounds of solid matter discharged in each 12,000 gallons of waste; 1.6 gallons of water per pound of wool scoured.

Plant No. 2. — Seventy-three hundred gallons of water per day used per 23,300 pounds of wool scoured, or 3.2 pounds per gallon of water; 7,415 pounds of solid matter per 12,000 gallons of waste.

Plant No. 3. — Twenty thousand gallons of water per day used; 9,281 pounds of solid matter per 12,000 gallons of waste.

Plant No. 4. — Thirty-seven thousand gallons of water per day used per 10,000 pounds of wool scoured, or 3.7 gallons per pound of wool; 54 gallons of water per pound of wool used in addition for washing the wool after scouring; 4,500 pounds of solid matter per 12,000 gallons of waste.

Plant No. 5. — Sixty-eight gallons of water used per pound of wool scoured and washed; 25,000,000 pounds of wool scoured per year.

Plant No. 6. — One hundred and fourteen thousand pounds of wool scoured per day; 0.56 of a gallon of water used per pound of wool scoured.

Filtration.

Experiments in 1895, 1896 and 1897 on the filtration of various wool wastes all resulted in failure when wool liquor alone was applied to the filter. This was to be expected owing to the general character of the wastes. Only when these wastes were mixed with large volumes of domestic sewage could they be successfully treated by intermittent filtration. When applied directly to sand or coke filters these wastes quickly clogged the surface, and the effluent did not differ in its general character from the applied waste. When clarified by various chemicals the liquor passed through the filters readily, but still remained practically unchanged. In fact, when applied in any considerable volume to a filter which was receiving domestic sewage, and which was in a state of active nitrification, it quickly checked this action. Filtration results were as follows: —

Filter No. 61. — This filter was $1/20000$ of an acre in area, and contained over the usual underdrains 60 inches in depth of sand of an effective size of 0.25 millimeter. The waste liquor from scouring wool was applied at an average rate of 17,000 gallons per acre daily. The results showed that while this liquor could be filtered through sand at this rate and a large percentage of its organic matters removed, yet the filter was operated with difficulty, owing to constant clogging, and a removal of the surface layers of sand was necessary repeatedly.

Average Analysis of Liquor applied to Filter No. 61.

[Parts per 100,000.]

Ammonia.		Chlorine.	Nitrogen as —		Oxygen Consumed.	Bacteria per Cubic Centimeter.
Free.	Albuminoid.		Nitrates.	Nitrites.		
17.30	43.10	60.13	.0000	.0000	232.00	–

Average Analysis of Effluent from Filter No. 61.

27.80	8.30	47.00	.2800	.0000	90.00	30,000,000

Filters Nos. VI. and VII. — Filter No. VI. contained 60 inches in depth of sand of an effective size of 0.25 millimeter, and Filter No. VII. contained the same depth of coke breeze. To these two filters the effluent from Filter No. 61 was applied at an average rate of 50,000 gallons per acre daily. Each filter disposed of the applied liquor readily, but it passed through the 5 feet of filtering material with very little or no change.

Average Analysis of Effluent from Filter No. VI.

[Parts per 100,000.]

Ammonia.		Chlorine.	Nitrogen as —		Oxygen Consumed.	Bacteria per Cubic Centimeter.
Free.	Albuminoid.		Nitrates.	Nitrites.		
[19.58	7.90	72.23	.2260	.0012	76.60	728,000

Average Analysis of Effluent from Filter No. VII.

21.17	8.39	54.06	.2200	.0260	76.10	472,000

Filter No. VIII. — This filter contained 5 feet in depth of sand of an effective size of 0.25 millimeter, and to it was applied the supernatant liquor resulting from removing much fat and dirt from the strong waste wool-scouring liquor when using calcium chloride as a precipitant. This treatment with calcium chloride gave an almost complete clarification of the liquor, and its strength after treatment, estimated by albuminoid ammonia determinations, was about the same as that of the effluent from Filter No. 61. Filter No. VIII. disposed of this clarified liquor readily at an average rate of 100,000 gallons per acre daily, but it passed through 5 feet of sand with very little change.

Average Analysis of Effluent from Filter No. VIII.

[Parts per 100,000.]

Ammonia.		Chlorine.	Nitrogen as —		Oxygen Consumed.	Bacteria per Cubic Centimeter.
Free.	Albuminoid.		Nitrates.	Nitrites.		
11.19	6.54	65.00	.1510	.0953	53.63	720,000

Analyses of Waste Liquor from a Second Plant. — Some complete analyses of waste liquor from a plant at which the liquor was more dilute than at Plant No. 1 resulted as follows: —

Analyses of Wool-scouring Liquor.

[Parts per 100,000.]

Residue on Evaporation.			Ammonia.				Chlorine.	Oxygen Consumed.
			Free.	Albuminoid.				
Total.	Loss on Ignition.	Fixed.		Total.	In Solution.	In Suspension.		
1,488	718	770	10.27	6.76	–	–	–	120.0
1,696	1,103	593	6.10	12.07	5.88	6.19	25.56	136.0

Filtration of Waste Wool Liquors from a Third and Fourth Plant. — An experiment was made upon the filtration of the entire waste flowing from a third plant, this waste including not only the liquor from scouring but also that from washing and rinsing. The filter contained 4½ feet in depth of sand of an effective size of 0.23 millimeter, but the waste passed through without nitrification. Afterwards, a small portion of city sewage, about one-fifth of the total volume of liquor applied to the filter, was added to the waste; nitrification became quickly established and the character of the effluent became much improved. It was possible to operate this filter at a rate exceeding 200,000 gallons per acre daily and still obtain a well-oxidized effluent. It was continued in operation for two years; then waste-scouring and washing liquor from a different establishment was mixed with the sewage and applied. It was still successful in causing purification. During the first three months of 1898 the filter was operated at a rate of 400,000 gallons per acre daily, the average analysis of the applied liquor and of the effluent being as follows: —

Average Analysis of Applied Liquor.

[Parts per 100,000.]

Ammonia.		Chlorine.	Nitrogen as —		Oxygen Consumed.
Free.	Albuminoid.		Nitrates.	Nitrites.	
1.95	.55	4.75	-	-	3.05

Average Analysis of Effluent.

0.44	.03	4.88	1.00	-	0.40

After this, the applied liquor was so changed that the mixture consisted of a strong *scouring* liquor mixed with city sewage, in the proportion of 1 part liquor to 17 parts sewage, and the rate of operation of the filter was reduced to 55,600 gallons per acre daily. The average analyses of the liquor applied to and of the effluent from this filter during the ensuing four months follow: —

[Parts per 100,000.]

	Ammonia.		Chlorine.	Nitrogen as —		Oxygen Consumed.
	Free.	Albuminoid.		Nitrates.	Nitrites.	
Applied liquor, . . .	4.10	2.15	9.76	-	-	19.62
Effluent, ...	2.37	1.02	9.61	.57	.0550	12.50

It will be seen that the character of the effluent of the filter deteriorated very decidedly during this period, although it was clear and almost colorless.

Application of Rotted Wool-Liquor. — During this period a sand filter of the same depth and grade of sand as the filter just mentioned was in operation. It received the same grade of mixed liquor at the same rate, but before application the mixture was allowed to stand forty-eight hours for anaerobic bacterial or rotting action to occur. The effluent from this filter was of a much better character, showing that the bacterial action which took place before application, like that which occurs in a septic tank, broke down the organic matter of the wool waste to such a degree that it was more easily nitrified.

Effluent from Filter receiving Rotted Liquor.

[Parts per 100,000.]

Ammonia.		Chlorine.	Nitrogen as —		Oxygen Consumed.
Free.	Albuminoid.		Nitrates.	Nitrites.	
.0694	.1134	7.30	3.75	.0075	1.66

Sedimentation.

When wool-scouring liquors are allowed to run into settling tanks, a considerable portion of the matter in suspension, such as sand, mineral matter, etc., washed from the wool, settles out. It is probably true, judging from our experiments, that in no case will more than 30 per cent. of the organic matter in suspension settle out within any reasonable length of time. Generally the percentage is not as large as this, inasmuch as the soapy and fatty matters present have a tendency to float and to hold up other matters in suspension.

Chemical Precipitation.

In the experimental treatment of these wool wastes about all the common precipitants were used, such as lime, ferric sulphate, ferric sulphate and lime, iron alum, aluminum sulphate, ferrous sulphate, ferric chloride, calcium chloride, etc. In all these experiments it was shown that a large amount of precipitant was needed to cause any coagulation whatever. Varying amounts of alum up to 30,000 pounds per million gallons often had little effect, and the same can be said of the addition of ferric sulphate. When ferric sulphate and lime were both added the amount necessary to cause a fair coagulation and precipitation was somewhat less. Treatment of some of these wastes with sulphate of alumina, at the rate of 50,000 pounds per million gallons, caused no precipitation beyond that given by sedimentation alone. With ferrous sulphate and ferric chloride some precipitation could be obtained by using 15,000 pounds per million gallons. Calcium chloride was more efficient than any of the other precipitants, but at least from 10,000 to 20,000 pounds per million gallons had to be used with a strong liquor. In the use of this precipitant the filtrate after precipitation was generally almost odorless.

The failure of precipitants to cause any satisfactory coagulation and precipitation of wool-scouring liquor, except when added in excessive amounts, is due to a number of causes. Inasmuch as the amount of organic and mineral matter present in the liquor is often from one hundred to three hundred times as great as is seen in ordinary domestic sewage, the necessity for an excessive use of precipitants is to be expected. There is, too, the difficulty due to the large amount of dirt. Much of the fatty matter in the liquor, furthermore, is in a state of semi-emulsion, and lighter than the water in which it is held; hence, any coagulation tends to gather this matter into masses containing a smaller percentage of water than before coagulation, and this coagulum, by reason of its buoyancy, carries some of the precipitants to the surface instead of being carried down by them. The experience at Lawrence has been similar to that at other places in the purification of such liquors by precipitation. At Bradford, Eng., the center of the English woolen trade, where it is calculated that 8 per cent. by volume of the sewage of the city comes from wool-washing establishments, it has been shown that from nine to twelve times as much precipitant is needed when treating week-day sewage as when treating Sunday sewage, free from this waste.

Straining through Coke and Cinders.

Experiments have shown that a considerable clarification can be obtained by passing these liquors to beds of coke or cinders; in fact, if the liquor is to be considered a sewage, and passed into the sewers of a town or city, the most successful method of treatment is undoubtedly by the combination of settling tanks and coke strainers, the mixture of the clarified effluent with the domestic sewage being passed to an ordinary filter bed.

At a fourth factory the liquors came from the processes of scouring wool, washing yarn, cloth-washing and dyeing, and the total volume amounted to 30,500 gallons per day, divided as follows: 21,000 gallons from wool-scouring, 2,100 from yarn-washing, 400 from cloth-washing and 7,000 from dyeing.

Acid Treatment.

Many examinations and experiments were made at the station with these liquors, and it was estimated from the analyses that the organic matter in them was equal to that in 200,000 gallons of domestic sewage such as flowed to the area to which it was proposed to pass these wastes. It was found that only about 20 per cent. of the organic matter in suspension would settle out in twenty-four hours; that the use of 25,000 pounds of sulphuric acid per million gallons of liquor treated caused good coagulation of the fatty matters and left the organic matter in such a condition that it could be filtered or strained easily, leaving a clear liquor. It was decided that if these wastes were passed through settling and acid treatment tanks they would then be sufficiently purified or freed from organic matters to pass the town sewers. The experiments showed that in this way about 70 per cent. of the organic matter and 90 per cent. of the fats present would be removed, and that by further treatment upon coke or sand strainers the removal of fatty matters would approximate 99 per cent. At many places abroad and at several places in this country — two in Massachusetts — this sludge is further treated in heated filter presses, to extract the grease. Grease extracted in this way in Massachusetts can be sold ordinarily for about 2 cents per pound.

New Processes.

Owing partly to the difficulty of treating this liquid like domestic sewage and partly to the fact that it contains a valuable amount of grease, ammonia and potash, many processes are being tried abroad in the hope that these various bodies can be saved. The old method of accomplishing partial recovery consists simply, as stated previously, in the application of sulphuric acid, by which the fats are to a certain extent coagulated and removed by settling tanks and strainers. A method of treatment said to be used abroad for the recovery of fats, soap, etc., is known as the Yaryan process. By this process the liquors from wool-scouring, cloth-washing, etc., after partial evaporation in a special form of evaporator, have the fats separated from the water by means of a centrifugal machine. The water after this separation is evaporated and the potassium carbonate recovered. The steam from this evaporation is sometimes condensed and the distilled water thus produced used for scouring, etc.

At one of the large mills at Lawrence, Mass., all the wool is now treated by a patented naphtha process, and it is stated that about 50,000 pounds of wool grease are saved each week. It is also stated by the mill authorities that the process is a profitable one, and that there is a ready sale for the grease produced. Of course, the naphtha treatment removes only fatty matters, etc., and a large amount of dirt still remains to be washed from the wool. Grease extracted from the wool by this naphtha process is said to command ordinarily a price about twice as great as that produced by acid treatment.

The following table shows the character of the strong waste wool-scouring liquor from several large woolen and worsted mills in Massachusetts. The figures given on the table are in each case the average of many analyses.

Average Analysis of Samples of Waste from Mill A.

[Parts per 100,000.]

Total Residue.		Loss on Ignition.		Free Ammonia.	Kjeldahl Nitrogen.		Oxygen Consumed.	Fats.
Total.	Dissolved.	Total.	Dissolved.		Total.	In Solution.		
9,554.2	4,038.2	7,331.0	2,446.0	10.94	132.6	65.5	574.7	5,135.0

Average Analysis of Samples of Waste from Mill B.

6,907.0	3,657.0	4,019.0	1,680.0	3.23	127.3	67.2	313.6	2,009.0

Average Analysis of Samples of Waste from Mill C.

21,790.3	4,759.3	7,861.3	2,401.3	15.73	229.9	86.9	938.3	4,150.0

Average Analysis of Samples of Waste from Mill D.

3,914.7	2,178.0	2,452.0	1,183.4	29.57	64.7	34.8	295.0	1,656.0

Woolen Mill Wastes.

The entire wastes from several woolen mills were studied at the station, with the following results: —

Mill No. 1.

The wastes from this mill consisted of water used in washing woolen cloth before dyeing, in dyeing the cloth and in washing the cloth after dyeing. The liquor from cloth-washing was the usual heavy, soapy liquid, rich in organic matter and containing much matter in suspension. The dyes used were generally of the aniline and black logwood varieties, the wastes being, therefore, generally black. In washing the cloth after dyeing, a solution of "black iron," consisting of muriatic acid, nitric acid, and copperas, was added to the water in which the cloth was washed. The total volume of waste water from this mill averaged from 150,000 to 200,000 gallons per day. The average waste varied in character according to the relative volumes of the different wastes coming from the mill, and was generally a black and very turbid liquid containing a large amount of matter in suspension. It did not putrefy, and much of the matter in suspension precipitated readily. Experiments with chemical precipitants showed that from 3,000 to 5,000 pounds of lime per million gallons of waste treated brought about good coagulation and precipitation, together with a removal of most of the coagulating matter. The use of 3,500 pounds of lime per million gallons of liquor caused the removal of 80 per cent. of the nitrogen determined as albuminoid ammonia, over 90 per cent. of the matters determined by the oxygen consumed test, together with about 70 per cent. of the organic and other matters determined by loss on ignition. As the volume of waste from this mill was about 200,000 gallons daily, about 700 to 1,000 pounds of lime would be required if chemical precipitation of the waste was followed, this meaning an expense of about $2 daily for lime.

Two small filters were operated at the station: to one (No. 301) the average waste was added at a rate of 100,000 gallons per acre daily for two months. Then for two months it was operated at a rate of 55,000 gallons per acre daily with the supernatant liquor after chemical precipitation. The effluent from this filter was always clear, light green in color and non-putrescible. The second filter (No. 303) was operated for four months at a rate of 100,000 gallons per acre daily, and received the supernatant liquor after sedimentation without chemical treatment. This filter also gave a clear, non-putrescible effluent, of a quality fully as good as that receiving the waste after treatment with chemicals. Each filter was constructed of 3 feet in depth of sand of an effective size of 0.28 millimeter.

The average analyses of the raw waste, of the waste applied to and of the effluent from each filter, together with the percentage removal of organic matter, are shown in the following table: —

Filter No. 301.

Waste.	Total Residue.	Total Loss on Ignition.	Ammonia.		Nitrogen as —		Oxygen Consumed.
			Free.	Albuminoid.	Nitrates.	Nitrites.	
Raw, . . .	118.7	47.6	.1200	.8900	-	-	19.86
Applied, . . .	166.4	13.1	.0747	.1340	-	-	2.90
Effluent, . . .	121.8	8.7	.0516	.0950	.07	.0062	1.57
Percentage removal: — By precipitation, .	-	72	38	85	-	-	85
By precipitation and filtration.	-	82	57	89	-	-	92
By filtration, . .	27	34	31	29	-	-	46

Filter No. 303.

Waste.	Total Residue.	Total Loss on Ignition.	Ammonia.		Nitrogen as —		Oxygen Consumed.
			Free.	Albuminoid.	Nitrates.	Nitrites.	
Raw, ...	118.7	47.6	.1200	.8900	-	-	19.86
Applied, . . .	123.9	28.5	.1013	.2960	-	-	11.90
Effluent, . . .	105.3	10.4	.0211	.0751	.00	.0002	2.37
Percentage removal: — By precipitation, .	-	40	16	67	-	-	40
By precipitation and filtration.	11	78	82	92	-	-	88
By filtration, . .	15	64	79	75	-	-	80

Mill No. 2.

The wastes from this mill were of four classes: (1) liquors from wool-scouring processes, (2) spent dye liquors, (3) wash water, (4) waste water from a shoddy mill. It was impossible to obtain an accurate estimate of the relative volumes of these wastes as the mill buildings covered a large area and were built over race-ways connecting the pond on one side of the mills with the river on the other side. The apparatus in the scouring department consisted of two sets of 4 tanks each, one set of 2 tanks and 6 large round kettles for carbonizing; in the dye-house there were 33 kettles for dyeing piece-cloth and 48 kettles for dyeing wool; in the washing department there were 40 washing machines, 7 of which were used in the neutralizing room; in the shoddy mill there were 3 beater-engines, similar to those used in paper mills, 2 shoddy scouring-tanks and 4 acid tanks. The volume of waste resulting from the apparatus used was about as follows: —

Process.	Gallons per Day.	
	Average.	Maximum.
1,	100,900	201,800
2,	1,569,400	2,186,400
3,	1,671,600	2,417,000
4,	36,400	100,500
Total,	3,378,300	4,905,700
Very Objectionable Wastes.		
1,	42,000	84,000
2,	161,600	242,400
3,	344,500	689,000
4,	8,900	17,900
Total,	557,000	1,033,300

Average samples of these wastes were sent to the experiment station in August, 1909. The samples as received were very highly colored, generally by a blue dye, and contained a large amount of organic and mineral matter in solution and in suspension. The average analyses of the waste before and after sedimentation follow: —

Raw Waste.

[Parts per 100,000.]

Unfiltered.			Filtered.			Ammonia.			Oxygen Consumed.
						Free.	Albuminoid.		
Total.	Loss on Ignition.	Fixed.	Total.	Loss on Ignition.	Fixed.		Total.	In Solution.	
150.0	60.0	90.0	108.0	30.2	77.8	.58	.80	.30	8.14
Settled Waste.									
94.1	26.9	67.2	–	–	–	.48	.31	–	3.61

Two filters, Nos. 380 and 381, were put into operation, receiving the supernatant waste after sedimentation. No. 380 was a trickling filter constructed of 6 feet in depth of broken stone, and No. 381 was constructed of 3½ feet in depth of sand with an effective size of 0.26 millimeter. The trickling filter (No. 380) was operated for seven weeks at rates varying from 500,000 to 750,000 gallons per acre daily. Its effluent was found to differ little in appearance and analysis from the applied waste. Filter No. 381 was first operated at a rate of 50,000 gallons per acre daily; then, after a few weeks, at a rate of 150,000 gallons per acre daily with the effluent from Filter No. 384. (See below.) Operated in this way, Filter No. 381 gave an effluent which was always clear and odorless, but more or less colored by the blue dye in the applied waste. A large part of the organic matter applied was removed by the filter, as is shown by the following average analysis of its effluent: —

Average Analysis of Effluent from Filter No. 381.

[Parts per 100,000.]

Ammonia.		Nitrogen as —		Oxygen Consumed.
Free.	Albuminoid.	Nitrates.	Nitrites.	
.3839	.0703	.37	.0092	1.29

Filter No. 384 contained 2 feet in depth of sand and was operated at a rate of 1,500,000 gallons per acre daily. After three weeks' operation the upper sand in the filter became badly clogged; 3 inches of sand were removed and a few days later the rate was reduced to 1,000,000 gallons per acre daily. Subsequently, when the surface sand became again badly clogged, the sand throughout the entire depth of the filter was examined, which examination showed that the clogging was confined practically to the upper 3 inches, and was due to fatty matters present in the wastes on account of the addition to these average wastes of those from wool-scouring. The fatty matters present in the upper 3 inches of sand averaged 500 parts per 100,000. The effluent from the filter was always clear and odorless, but had considerable color. The average analysis of its effluent for the two months of its operation was as follows: —

Average Analysis of Effluent from Filter No. 384.

[Parts per 100,000.]

Ammonia.		Nitrogen as —		Oxygen Consumed.
Free.	Albuminoid.	Nitrates.	Nitrites.	
.2347	.1614	.03	.0004	1.88

The experiments with the wastes from this mill indicated that they could be purified without any great difficulty to a degree sufficient to allow their entrance into the river without nuisance, by a sand filter, or strainer, operated at a rate of 500,000 gallons per acre daily, with the production of an effluent containing but a small percentage of the organic matter in the original waste. The waste before passing to such a filter should have passed through ample settling basins to allow time for the sedimentation of the large amount of matter in suspension, and the waste from the wool-scouring processes should have received separate treatment to remove the fatty matters before being mixed with the remaining wastes from the mill.

Mill No. 3.

The wastes discharged from this mill came from the processes of washing, boiling and dyeing heavy woolen cloth, the total volume of waste amounting to between 30,000 and 35,000 gallons daily. Aniline dyes were used. The process of washing after dyeing covered a period of from one and one-half hours to two hours. The first waste wash-water discharged was dirty and black, and contained large quantities of heavy suspended matter. During the rest of the washing period the water was much clearer, and contained but small amounts of matters in suspension. The total waste water from the mill consisted of approximately 1 part of spent dye liquor to 13 parts of the water from cloth-washing.

In 1906 two filters were put into operation at the station to receive this waste. Filter No. 307 contained 3 feet in depth of sand of an effective size of 0.28 millimeter, and was operated at a rate of 100,000 gallons per acre daily with the supernatant liquor after treatment with 5,000 pounds of lime and 5,000 pounds of copperas per million gallons. The effluent from the filter was always slightly turbid and of a light green color, but was non-putrescible. After a few weeks' operation the rate of this filter was reduced to 50,000 gallons per acre daily, with much better results. Average analyses of the waste before chemical treatment, of the waste after chemical treatment, and of the effluent from the filter follow.

To Filter No. 308, containing 4 feet in depth of sand of an effective size of 0.25 millimeter, the supernatant liquor after sedimentation only was applied, first at a rate of 100,000 gallons per acre daily and later at a rate of 50,000 gallons per acre daily. The effluent from this filter was always clearer than that of the filter receiving the treated waste, was less turbid, had less color, and was always non-putrescible.

The average analyses of the waste before sedimentation, after sedimentation and of the effluent from the filter follow.

Filter No. 307.

[Parts per 100,000.]

Waste.	Total Residue.	Total Loss on Ignition.	Ammonia.		Nitrogen as —		Oxygen Consumed.
			Free.	Albuminoid.	Nitrates.	Nitrites.	
Raw, ...	270.4	121.5	.3900	2.1900	–	–	18.13
Applied, . . .	234.8	66.9	.4233	0.6700	–	–	11.13
Effluent, . . .	176.8	21.8	.0354	0.1465	.10	.0028	1.93
Percentage removal, .	–	67.4	–	78.1	–	–	82.7

Filter No. 308.

Waste.	Total Residue.	Total Loss on Ignition.	Ammonia, Free.	Ammonia, Albuminoid.	Nitrogen as Nitrates.	Nitrogen as Nitrites.	Oxygen Consumed.
Raw, ...	270.4	121.5	.3900	2.1900	–	–	18.13
Applied, . . .	264.5	111.1	.3867	0.9500	–	–	14.20
Effluent, . . .	147.6	17.5	.0128	0.0775	.00	.0001	1.50
Percentage removal, .	–	84.2	–	91.8	–	–	89.4

The experiments carried on at Lawrence indicated that the waste water could be satisfactorily treated by means of plain sedimentation followed by intermittent filtration through 3 or 4 feet of moderately fine sand, at a rate not exceeding 50,000 gallons per acre daily.

Mill No. 4.

The wastes from this mill came from the processes of washing and dyeing cloth and dyeing raw cotton. In cloth-washing the cloth is first saturated with soap in the fulling machines and then washed for a period of from twenty to thirty-five minutes. The total amount of wash-water from this process was between 30,000 and 40,000 gallons daily. From 12,000 to 15,000 gallons of this contained considerable soap, the remainder being practically clear. The dyes used were heavy logwood and aniline dyes, and the waste discharged consisted of the spent dye liquor together with the rinse water. The total volume of water from dyeing and rinsing amounted to about 21,000 gallons per day. The worst wastes discharged from the mill consisted of from 12,000 to 15,000 gallons of wash-water used in washing cloth and about 12,000 gallons of spent dye liquor per twenty-four hours.

On Oct. 22, 1906, a mixture of the worst wastes from the mill was applied after sedimentation to a filter (No. 320) containing 3 feet in depth of sand of an effective size of 0.25 millimeter, at a rate of 100,000 gallons per acre daily. This waste was very turbid, pinkish in color, non-putrescible, and deposited only a small amount of matter when allowed to stand. Eighty-five per cent. of the organic matter in the applied waste as shown by albuminoid ammonia determinations, and 89 per cent. as shown by the oxygen consumed results, were removed by the filter. The effluent was clear, colorless and non-putrescible.

The average analyses showing these results follow: —

Average Analysis of Waste Liquor, Filter Effluent and Percentage Removal of Organic Matter.

Filter No. 320.

Waste.	Total Residue.	Total Loss on Ignition.	Ammonia.		Nitrogen as —		Oxygen Consumed.
			Free.	Albuminoid.	Nitrates.	Nitrites.	
Raw,	162.3	62.4	.1000	.5830	-	-	11.40
Applied,	150.6	54.6	.0700	.3400	-	-	8.47
Effluent,	115.3	12.6	.0280	.0514	.01	.0023	0.97
Percentage removal: — By sedimentation,	7	12	30	42	-	-	22
By sedimentation and filtration.	29	80	72	91	-	-	91
By filtration,	23	77	60	85	-	-	89

The plans for the purification of these wastes showed two sand filter beds having a combined area of half an acre, these beds to be under-drained by tile pipe $3\frac{1}{2}$ feet below the surface of the sand. This area seemed to be ample for the treatment of the waste liquor from this mill. With a total volume of 30,000 gallons per day, the rate of filtration through these beds would be 60,000 gallons per acre daily, and although the amount of matter settling from these wastes was slight, some provision for sedimentation seemed desirable.

Carpet Mill Wastes.

During 1904, 1905 and 1906 investigations were carried on by the Board in regard to the wastes at the works of a carpet company. The principal wastes were from the processes of scouring wool, yarn, etc., and had the general appearance and character of such wastes; that is, they were heavy, soapy liquids, semi-emulsions of fat, dirt and soap, and containing a large amount of solid matter, sometimes 2,000 or 3,000 parts per 100,000 parts, or seventy to one hundred times as much as an ordinary Massachusetts domestic sewage. They contained, also, an amount of organic matter determined as albuminoid ammonia often ten to twenty times as great as that in average domestic sewage, and the organic matter, as shown by the determination of oxygen consumed, was correspondingly high.

Measurements made in 1904 of the amount of waste from the various machines at the mill follow: —

Source of Waste.	Gallons per Day.	Source of Waste.	Gallons per Day.
Strip washer,	3,850	Yarn washer No. 2,	1,047
Drum sheet tank,	353	Centrifugal washer,	3,000
Sheet washer tank,	270	Wool-dyeing machine,	2,950
Sheet washer (continuous flow),	14,600	Brussels yarn dye tubs, blue and black,	1,140
Hot washer and paste barrels,	150	Washing tank (continuous flow),	3,270
Wool-scouring machine,	1,700	Blue dye washing machine,	13,730
Brussels dye tubs,	7,460	Yarn dyers (three),	15,550
Yarn rinse box,	10,500	Wool-dyer machine (rinsing),	2,950
Yarn washer No. 1,	1,047		

Measurements made in 1908 showed the total volume to be much larger than that of 1904, but this increase was due largely to the use of clear water in the discharge pipes of the mill for the purpose of flushing. The actual volume of waste from the mill, not including this fairly clear water, was probably from 110,000 to 114,000 gallons per twenty-four hours.

In October, 1904, experiments were begun with the wastes from this plant. The waste dye liquors were densely colored, with green and red hues predominating, and were generally acid. Mixtures of the various wastes, made in proportions corresponding to the volume of each as it flowed from the mill, gave a liquor exceedingly rich in organic matter and of a green color. This mixed liquor was alkaline, owing to the large volume of wool-scouring liquor present, and this was the waste upon which the experiments upon sedimentation, chemical precipitation and filtration were made. It was found that by allowing the mixed or average waste liquor to stand for twenty-four hours there was removed by sedimentation about 50 per cent. of the total nitrogenous organic matter present and about 60 per cent. of the total organic matter. Ordinary coagulants, except in excessive and costly amounts, had comparatively little effect on the organic matter left after this sedimentation. Copperas and lime, when applied at the rate of 2,500 pounds of each per million gallons of liquor, reduced the nitrogenous matter left in the supernatant liquor after sedimentation about 23 per cent., and the total organic matter 35 per cent. The same precipitants, when used at the rate of 5,000 pounds per million gallons, reduced the nitrogenous matter 34.5 per cent., and the total organic matter remaining 50 per cent.

Seven filters, constructed of different filtering materials were started and kept in operation for five weeks, for the purpose of studying the most suitable and efficient method for the filtration of these wastes. Three of these were constructed of sand of an effective size of 0.33 millimeter, and were operated at rates varying from 100,000 to 500,000 gallons per acre daily. The other four filters were constructed of cinders, soft coal, coke breeze and charcoal, respectively, and each was operated at the rate of 500,000 gallons, with the exception of the cinder filter, which was operated at a rate of 1,000,000 gallons per acre daily with the supernatant liquor after twenty-four hours' sedimentation of the waste. These experiments showed that sand filtration at a comparatively low rate gave the best purification; that by chemical precipitation followed by sand filtration at a rate higher than that usual with filters receiving the supernatant liquor from simple sedimentation more organic matter could be removed, but not enough more to compensate for the chemicals used; that with a cinder filter operated at a 1,000,000-gallon rate purification nearly as good could be obtained as that with the low-rate sand filter, but that excessive clogging necessitated frequent removal of filtering material; that a coke breeze filter at a 500,000-gallon rate gave as good results as a cinder filter at a 1,000,000-gallon rate, and nearly as good results as the low-rate sand filter;

and that none of the filters removed much of the green color of the applied liquor.

In December, 1905, additional experiments were begun, and six filters were put into operation, receiving the supernatant liquor after sedimentation of the entire waste, one being constructed of cinders and the others of sand, and these filters were continued in operation for nearly seven months. A filter constructed of 18 inches in depth of cinders was operated at a rate of 500,000 gallons, and its effluent was applied to a filter constructed of 27 inches in depth of sand and operated at a rate of 100,000 gallons per acre daily. This combination of filters removed from the applied liquor 62 per cent. of the nitrogen determined as albuminoid ammonia, 62 per cent. of the organic nitrogen, 65 per cent. of the organic matter determined as oxygen consumed, 23 per cent. of the total solids, and 56 per cent. of the combustible solids.

A second combination, consisting of three sand filters of equal areas and each constructed of 3½ feet in depth of sand, was put into operation at the same time, the supernatant liquor after sedimentation being applied to the first of these sand filters at a rate of 100,000 gallons per acre daily, the effluent from the first filter to the second, and the effluent from the second to the third. As a result of this experiment the percentage removal of the organic matters, etc., in the applied liquors was as follows: —

Per Cent. Removed.

Filter No.	Ammonia.		Kjeldahl Nitrogen.	Oxygen Consumed.	Solids.		
	Free.	Albuminoid.			Total.	Loss.	Fixed.
293, ...	53	56	66	65	24	53	7
293 and 294, . .	77	71	77	76	40	72	22
293, 294 and 295, .	78	81	86	84	51	79	33

During the same period a filter of the same depth of sand, Filter No. 296, was operated at one-third the rate of each of the three filters just described, namely, 33,300 gallons per acre daily, this rate giving the same rate per unit of surface as the combination just described. The percentage removal of matter present in the applied liquor was as follows, and was practically the same as that of the three filters operated at higher rates: —

Filter No. 296. — Per Cent. Removed.

Ammonia.		Kjeldahl Nitrogen.	Oxygen Consumed.	Solids.		
Free.	Albuminoid.			Total.	Loss.	Fixed.
76	78	84	82	46	72	30

The effluents from all these filters, with the exception of the shallow cinder filter, were clear and generally green in color. They were perfectly stable, no putrefaction ensuing when kept in the warm laboratory for weeks, although the waste itself quickly putrefied. The work done by all these filters improved steadily, nitrification taking place in each of them during the last two months of operation.

The results of the work carried on with these wastes during the period described appeared to prove that an effluent of good quality could be obtained by the use of settling tanks holding one day's flow from the mill, this to be followed by sand filtration of the supernatant liquor at a rate as high as 50,000 gallons per acre daily, the sedimentation removing about 50 per cent. of the total organic matter present and filtration removing about 75 per cent. of that remaining.

Average Analyses. — Untreated Waste Liquor.

[Parts per 100,000.]

Residue.		Loss on Ignition.		Ammonia.			Kjeldahl Nitrogen.	Chlorine.	Oxygen Consumed.
				Free.	Albuminoid.				
Total.	Dissolved.	Total.	Dissolved.		Total.	Dissolved.			
425.6	331.0	230.1	141.8	1.66	2.52	0.85	4.87	5.06	49.37

Filter No. 284. — Applied Waste Liquor. (Supernatant after Twenty-four Hours' Sedimentation.)

[Parts per 100,000.]

Solids.			Ammonia.		Kjeldahl Nitrogen.	Nitrates.	Oxygen Consumed.
Total.	Loss.	Fixed.	Free.	Albuminoid.			
200.7	89.7	111.0	.6243	.8488	1.9517	-	12.56

Filter No. 284.[1] *— Effluent.*

[Parts per 100,000.]

Solids.			Ammonia.		Kjeldahl Nitrogen.	Nitrates.	Oxygen Consumed.
Total.	Loss.	Fixed.	Free.	Albuminoid.			
147.1	42.9	104.2	.4525	.4789	1.1195	.05	8.24

Filter No. 285.[2] *— Effluent.*

129.9	18.2	111.7	.2145	.2187	0.6452	.17	3.64

Filter No. 293.[3] *— Effluent.*

137.6	21.3	116.3	.5275	.2455	0.4338	.05	3.82

Filter No. 294.[4] *— Effluent.*

118.3	12.4	105.9	.0911	.1568	0.2911	.32	2.35

Filter No. 295.[5] *— Effluent.*

101.2	10.4	90.8	.0679	.1126	0.1853	.38	1.77

Filter No. 296.[6] *— Effluent.*

112.7	14.1	98.6	.1189	.1312	0.2036	.30	2.17

1 Filter No. 284, started Dec. 15, 1905. Contained 18 inches in depth of cinders passing a 4-inch mesh and held back by a 6-inch mesh. Rate, 500,000 gallons per acre daily. January 26 rate was decreased to 250,000 gallons per acre daily.

2 Filter No. 285 contained 27 inches in depth of sand of an effective size of 0.28 millimeter. Started Dec. 15, 1905. Operated at a rate of 100,000 gallons per acre daily, receiving the effluent from Filter No. 284.

3 Filter No. 293 contained 3½ feet in depth of sand of an effective size of 0.28 millimeter. Started Jan. 29, 1906. Operated at a rate of 100,000 gallons per acre daily with supernatant liquor after twenty-four hours' sedimentation.

4 Filter No. 294 was a duplicate in construction of Filter No. 293. Operated at a rate of 100,000 gallons per acre daily with the effluent from Filter No. 293.

5 Filter No. 295 was a duplicate in construction of Filter No. 293. Operated at a rate of 100,000 gallons per acre daily with the effluent from Filter No. 294.

6 Filter No. 296 was a duplicate in construction of Filter No. 293. Operated at a rate of 33,000 gallons per acre daily, receiving supernatant waste after sedimentation.

Waste Liquors from Paper Mills.

The waste liquors from paper mills can be divided into two groups, the first including the waste liquors from washing and preparing the stock, and the second including waste liquors produced in working this stock up into paper. The volume of the liquors from washing and preparing the stock is much smaller than that used in the process of manufacture, but it contains a much larger percentage of organic matter. The total volume of waste liquors discharged from a paper mill is generally very large. This volume in 1895 from two plants, taken as good examples of the paper-making industry in Massachusetts, varied in both cases between 2,000,000 and 3,000,000 gallons per day. In one plant there was worked up yearly about 5,100 tons of a stock consisting largely of old paper, but including a considerable amount of old rope and bagging, and also a small amount of old oilcloth. In making this stock into paper about 1,000 tons of chemicals and dyestuffs were used yearly, consisting of alum, quicklime, chloride of lime or bleach, soda ash, copperas, china clay, caustic soda, starch, aniline dyes, bichromate of lead, etc. The second mill investigated as to the volume of its waste liquor produced about 4,000 tons of paper yearly, and used also a very large amount of chemicals, dyestuffs, etc. The waste liquors produced by boiling rags in caustic soda, caustic lime, or mixtures of soda ash and lime, in order to free them from grease, dirt and coloring matter, are of such composition that it is practically impossible to purify them by intermittent filtration. A sand filter operated at the station in 1895, to which such a liquor was applied, gave very poor results, and other experiments made since that date with like liquors have resulted similarly.

The following table gives the average analysis of the liquor applied to and of the effluent from the filter mentioned, — Filter No. 60, $1/20000$ of an acre in area and containing 5 feet in depth of sand of an effective size of 0.25 millimeter. It was operated at the rate of 65,000 gallons per acre daily.

Average Analysis of Liquor Applied to Filter No. 60.

[Parts per 100,000.]

Ammonia.		Chlorine.	Nitrogen as —		Oxygen Consumed.	Bacteria per Cubic Centimeter.
Free.	Albuminoid.		Nitrates.	Nitrites.		
2.30	5.10	20.00	.0000	.0000	140.00	-

Average Analysis of Effluent from Filter No. 60.

1.09	2.29	12.59	.1050	.0067	84.36	3,092,000

Continued experimentation made it clear that the only satisfactory method of treatment of the strong alkaline liquor alone was by evaporation and by recovery of chemicals, and this method is used in many places at home and abroad.

An average analysis made in 1895 of the mixed waste liquors from each of the mills mentioned above resulted as follows: —

Mill No. 1.

[Parts per 100,000.]

Solids.		Ammonia.		Chlorine.	Oxygen Consumed.
Total.	Loss on Ignition.	Free.	Albuminoid.		
43.00	20.00	.0200	.1500	1.00	3.00
Mill No. 2.					
51.00	31.00	.0150	.1500	1.50	4.00

Experiments made in 1895 and 1896 showed that either or both of these liquors could be passed through sand filters at rates of from 200,000 to 400,000 gallons per acre daily, with a clear, bright and well-purified effluent as a result. Little nitrification occurred in the sand filters receiving such liquor, and the fibrous matter in it, of which the chief organic pollution was composed, formed a mat over the surface of the filter often tenacious enough to hold together and to be easily rolled up and removed. The average analysis of the effluent from a sand filter, containing 4.5 feet in depth of sand of an effective size of 0.23 millimeter, which received the mixed liquors of the composition shown above and at the rates mentioned, was as follows: —

Effluent from Filter No. 77.

[Parts per 100,000.]

Ammonia.		Chlorine.	Nitrogen as —		Oxygen Consumed.
Free.	Albuminoid.		Nitrates.	Nitrites.	
.0086	.0219	1.31	.0096	.0024	.34

Straining through Coke.

In order to test the value of coke as a strainer in removing the impurities from these paper mill liquors, a small coke strainer, $\frac{1}{20000}$ of an acre in area, was kept in operation at one of the mills for a period of several months. To this strainer liquors from all the processes of washing and manufacture of paper at the mill were applied, and the rate of operation varied from 500,000 to 2,000,000 gallons per acre daily. It gave a uniformly clear, practically colorless effluent, and there was deposited upon its surface a large accumulation of dirt, fibrous matter, etc., which was rolled up from time to time and removed. A cinder strainer was equally efficient.

A small coke strainer to which these liquors were applied was kept also in operation at the station for a period of several months, at the rate of 1,000,000 gallons per acre daily. The effluent of the strainer was clear, almost colorless and contained little organic matter. The average analysis during its period of operation, when receiving the mixed liquor, was as follows: —

Effluent from Coke Strainer No. 77A.

[Parts per 100,000.]

Ammonia.		Chlorine.	Nitrogen as —		Oxygen Consumed.
Free.	Albuminoid.		Nitrates.	Nitrites.	
.0161	.0311	2.10	.0064	.0019	.87

Screening, Sedimentation and Chemical Precipitation.

Much of the organic pollution in the mixed liquors is in suspension, and is quite readily removed by passing the liquors through fine wire screens. In some mills a considerable portion of fine pulp which passes through the paper machines is saved in this way, and it is evident that a large part of the dirt in the various wash waters can be screened out in the same way. Results obtained by sedimentation showed that about 30 per cent. of the total organic pollution could be removed from the waste liquors if they were allowed to settle for one hour, but that considerably longer periods of sedimentation failed to give much better reresults. With precipitants such as ferrous or aluminum sulphate, in the proportion of 500 pounds per 1,000,000 gallons of liquor treated, about 45 per cent. of the organic matters was removed.

Further Experiments with Wastes from Paper Mills.

Ten years later, in 1905 and 1906, the waste liquors from the two paper mills previously mentioned were again experimented with, and also the liquors from a third paper mill, with the following results: —

Paper Mill A.

The stock employed at this mill was made up of old manilla and jute rope and old bagging in proportions varying with the quality of paper produced, but averaging 52,000 pounds of rope and 6,000 pounds of bagging during each twenty-four hours. The stock is cut very fine and dusted, thereby losing much of its dirt. It is then boiled about nine hours in a rotary boiler under forty-five pounds' steam pressure, in the presence of large but varying amounts of lime and soda. Every morning these boilers are blown off, the stock is dumped and allowed to drain. In its pulpy condition the stock is then put into washing machines and washed three to four hours. It is bleached at the end of the wash, if necessary, by pickling in washing machines with bleaching liquor, and is then transferred to draining chambers. Some of the stock is used directly for paper after being beaten and ground, while some receives a second wash, and, after being beaten and ground, is run up on a paper machine.

The materials used in this mill averaged at the time of these experiments about as follows per twenty-four hours: —

52,000 pounds of old manilla and jute rope.
6,000 pounds of old bagging.
5,400 pounds of lime.
600 pounds of soda ash.
1,400 pounds of bleaching powder.
1,500 pounds of white clay.
250 gallons of sizing solution, dyes, etc.

The volumes of waste liquors from the mill per day were about as follows: —

30,000 gallons of boiler waste.
900,000 gallons of water used in washing the stock from the boilers.
75,000 gallons from draining chambers.
200,000 gallons from the stock washed a second time.
500,000 gallons from paper machines.
150,000 gallons from cleaning the mechanical filters.

The waste liquors were divided into three classes: boiler wastes, washing-machine wastes and paper-machine wastes. Two large settling tanks and a number of experimental filters were constructed and put into operation at this mill in July, 1905, and the experiments were continued until November, 1906. Until Dec. 15, 1905, the liquor experimented with was made up of the boiler and machine wastes mixed in proper proportions. The two settling tanks put into operation, namely A and B, were each 9 feet in diameter at the bottom, 8 feet at the top and 8¾ feet deep; and the capacity of each was approximately 3,400 gallons. Each tank had three vertical partitions about 1½ feet apart, stretching across the tank and extending downward from the surface of the water about 3 feet, in order to break the current between the inlet and outlet pipes. The outlet of each tank was a siphon arranged to draw the waste a short distance below the surface. During the first period of operation of these tanks they received mixed rotary wastes and washing-machine wastes, with the result that little sedimentation occurred. During a period of five months in 1906, however, the tanks received the waste liquor from the washing machines only, and during this time they removed 39 per cent. of the organic matter determined as loss on ignition and 32 per cent. determined as albuminoid ammonia. The analyses of the liquor entering and of the effluent from these tanks during this latter period follow: —

Tanks treating Paper Mill Waste.—Average Analyses and Percentage Removal for the Months of June to October, inclusive.

Tank A.

	Residue.		Loss on Ignition.		Ammonia.				Oxygen Consumed.	
						Albuminoid.				
	Total.	Dissolved.	Total.	Dissolved.	Free.	Total.	Dissolved.	Suspended.	Unfiltered.	Filtered.
Applied water,	162.65	80.91	81.28	37.98	.0553[1]	.4355	.2675	.1680	31.87	17.06
Effluent,	95.41	58.33	49.63	30.06	.0292[1]	.2959	.1963	.0997	19.89	12.53
Percentage removal,	41.3	27.9	38.9	20.8	47.2[1]	32.1	26.6	40.7	37.6	26.5

Tank B.[2]

Applied water,	144.43	69.77	74.33	32.95	.0299[3]	.2930	.1829	.1095	29.75	14.05
Effluent,	84.26	54.97	44.72	28.53	.0104[3]	.2433	.1697	.0725	29.08	19.37
Percentage removal,	41.7	21.2	39.8	13.4	63.2[3]	17.0	7.2	33.8	2.3	—37.9

[1] July 1 to October 31. [2] June to September 30. [3] July 1 to September 30.

Filters Nos. 1 and 2. — Two filters, each 1/217 of an acre in area, were put into operation in July, 1905, and were operated until November, 1906. Filter No. 1 was constructed of 20 inches in depth of cinders and

Filter No. 2 of from 25 to 30 inches in depth of sand of an effective size of 0.20 millimeter. Each filter received, until December, 1905, the mixture of boiler and washing-machine waste coming from the settling tanks. After that date each filter received the waste liquor from the washing machines after this waste had passed through the settling tanks. Each filter was operated intermittently at rates varying from 200,000 to 1,000,000 gallons per acre daily, but it became evident that the maximum rate at which they could be operated with good results was from 200,000 to 300,000 gallons per acre daily. Filter No. 1 removed during its period of operation 54 per cent. of the applied organic matter as shown by the loss on ignition determinations and 55 per cent. of the nitrogenous matters as shown by determinations of albuminoid ammonia. Filter No. 2 removed 59 and 60 per cent., respectively, of the organic matter as shown by similar determinations. Each filter when operated at a reasonable rate produced a non-putrescible effluent. Each filter required raking several times during its period of operation, and from Filter No. 2, 3 inches in depth of sand were removed on Oct. 27, 1905.

The average analysis of the effluent from each of these two filters follows: —

Effluent from Filter No. 1.

[Parts per 100,000.]

Total Residue.	Total Loss on Ignition.	Ammonia.		Oxygen Consumed (Unfiltered).
		Free.	Albuminoid.	
76.23	27.52	.0869	.1520	8.44

Effluent from Filter No. 2.

69.23	24.23	.0725	.1373	7.65

Other filters also were operated at this time, some being constructed of sand and others of gravel. The gravel filters were operated as trickling filters at rates varying from 2,000,000 to 4,000,000 gallons per acre daily. Filter No. 1, as stated above, was $\frac{1}{217}$ of an acre in area and constructed of from 18 to 20 inches in depth of cinders with an effective size of 0.20; Filter No. 2 was $\frac{1}{217}$ of an acre in area, constructed of from 25 to 30 inches in depth of sand of an effective size of 0.20 millimeter; Filter No. 3 was $\frac{1}{875}$ of an acre in area and contained 30 inches in depth of fine sand of an effective size of 0.20 millimeter, underlaid with coarse gravel; Filter No. 4 was a trickling filter, $\frac{1}{20000}$ of an acre in area, and contained

5 feet in depth of gravel, all of which had a diameter less than 33 millimeters and none less than 6 millimeters, the effective size being about 10 millimeters; Filter No. 5 was a duplicate of No. 4; Filter No. 8 was $\frac{1}{10000}$ of an acre in area and constructed of 20 inches in depth of fine sand of an effective size of 0.15 millimeter; Filter No. 10 was $\frac{1}{272}$ of an acre in area and constructed of 6 feet in depth of small stones from $\frac{1}{4}$-inch to 3 inches in diameter; and Filter No. 11 was $\frac{1}{20000}$ of an acre in area and constructed of 8 feet in depth of coarse gravel similar to that in Filter No. 10.

The results obtained with most of these smaller filters, both sand and trickling, were of little value except in a negative way. The effluents from the trickling filters were generally putrescible, and those from the shallow sand filters, containing only a few inches in depth of sand, were little, if any, better. The best result was obtained from Filter No. 8. This filter was operated at a rate of 500,000 gallons per acre daily, and was dosed intermittently during nine hours of the day, being flooded every half-hour with the effluent from Filter No. 11, a filter operated as a trickling filter at a rate of 2,000,000 gallons per acre daily. The effluent from Filter No. 11 was always putrescible, but that from Filter No. 8 was clear and non-putrescible. Filter No. 11 was operated without difficulty for six months in 1906.

The average analyses of the applied waste and of the effluent, and figures showing the percentage of purification of each of these filters, follow: —

Average Analyses and Percentage Removal for the Months of June to October, inclusive.

Filter No. 1.

	Total Residue.	Total Loss on Ignition.	Ammonia.		Oxygen Consumed. (Unfiltered).
			Free.[1]	Albuminoid.	
Applied water,	95.41	49.63	.0292	.3578	19.89
Effluent,	46.84	16.56	.0080	.0909	4.01
Percentage removal,	50.9	66.6	72.6	71.8	79.8

Filter No. 2.

	Total Residue.	Total Loss on Ignition.	Ammonia. Free.[1]	Ammonia. Albuminoid.	Oxygen Consumed. (Unfiltered).
Applied water,	95.41	49.63	.0292	.3578	19.89
Effluent,	45.04	15.71	.0053	.0705	3.21
Percentage removal,	52.8	68.3	81.8	80.3	3.21

[1] July to October.

Average Analyses and Percentage Removal for the Months of June to October, inclusive — Concluded.

Filters Nos. 5 and 4.

	Total Residue.	Total Loss on Ignition.	Ammonia.		Oxygen Consumed (Un-filtered).
			Free.[1]	Albuminoid.	
Applied water, . . .	91.88	47.23	.0292	.2811	19.17
Effluent, ...	49.38	20.27	.0106	.1401	7.91
Percentage removal, . .	46.3	57.1	63.7	50.2	58.7

Filter No. 5.

Applied water, . . .	91.88	47.23	.0292	.2811	19.17
Effluent, ...	67.39	33.61	.0181	.1997	14.02
Percentage removal, . .	26.7	28.8	38.0	29.0	26.9

Filter No. 4.

Applied water, . . .	67.39	33.61	.0181	.1997	14 02
Effluent, ...	49.38	20.27	.0106	.1401	7.91
Percentage removal, . .	26.7	39.7	41.4	29.8	43.6

Filter No. 10.

Applied water, . . .	86.93	47.49	.0218	.2624	27.99
Effluent, ...	64.17	32.09	.0138	.1926	12.67
Percentage removal, . .	26.2	32.4	36.7	26.6	54.7

Filter No. 11.

Applied water, . . .	86.93	47.49	.0218	.2624	27.99
Effluent, ...	57.83	27.42	.0147	.1822	11.96
Percentage removal, . .	33.5	42.3	32.6	30.6	57.3

Filter No. 8.

Applied water, . . .	57.83	27.42	.0147	.1822	11.96
Effluent, ...	39.97	14.65	.0069	.0673	2.89
Percentage removal, . .	30.9	46.6	53.1	63.1	75.8

[1] July to October.

Paper Mill B.

This mill made approximately 25 tons of white magazine paper during every twenty-four hours. At the time of the experiments the stock used consisted of prepared wood pulp and rags, the amount of rags varying from 5 to 15 per cent. of the total stock used. But one rotary boiler was used at the mill, and this was emptied but three or four times a week, making the daily volume of boiler waste about 1,500 gallons. Lime only was used in the boiler, the amount being about 1,200 pounds at each charge. Considerable bleaching powder was used at the mill, also large amounts of china clay and size, as the product was a high-grade white paper. The total volume of waste water from the washing machines was about 400,000 gallons per day; that from the paper machines was much larger, but was almost all reclaimed, so that its treatment did not require attention.

An experimental plant was put into operation in December, 1905, consisting of one settling tank and one filter. The first experiments were made upon filtration of both boiler and washing-machine wastes, but they were unsuccessful. After May 17 the waste water experimented with was that from the washing machines only.

The settling tank was $5\frac{1}{2}$ feet in diameter and 5 feet deep, holding 900 gallons, and was similar to Tanks A and B at the experimental plant of Paper Mill A. The tank was so operated that the time of passage of the waste liquor was approximately five hours during the period from December, 1905, to September, 1906. The rate of flow was then so increased that the waste took only two and one-half hours to pass through the tank. Analyses showed that this tank removed 79 per cent. of the total solid matter; 75 per cent. of the organic matter, as shown by loss on ignition; 75 per cent. of the nitrogenous organic matters, determined as albuminoid ammonia, and 78 per cent. of the organic matters determined by the oxygen consumed test. The tank was cleaned May 17, July 7, September 13 and October 9. The filter used was 11 feet in diameter, or $\frac{1}{450}$ of an acre in area, and was constructed of 24 inches in depth of screened cinders with an effective size of 0.20 millimeter. It received the effluent from the settling tank from December, 1905, to September, 1906, at a rate of 900,000 gallons per acre daily. The rate was then increased to 1,500,000 gallons per acre daily. The filter was raked three times during its period of operation and the material was scraped from it but once. This filter received the washing-machine waste, was very efficient and gave an effluent that was clear, practically colorless, odorless and non-putrescible.

The average analyses of the applied waste and of the effluents from both the settling tank and filter follow: —

Average Analysis of Waste Liquor applied to Settling Tanks.

[Parts per 100,000.]

Residue.		Loss on Ignition.		Ammonia.				Oxygen Consumed.	
				Free.	Albuminoid.				
Total.	Dissolved.	Total.	Dissolved.		Total.	Dissolved.	Suspended.	Unfiltered.	Filtered.
200.53	104.86	58.93	31.27	.2313	.4187	1.1950	.2237	20.30	12.29
Average Analysis of Effluent from Settling Tank.									
41.17	29.73	14.59	10.42	.0857	0.3533	0.4884	.0557	4.36	3.31
Average Analysis of Waste Liquor applied to Filter.									
40.79	-	15.01	-	.0755	0.3157	-	-	4.15	-
Average Analysis of Effluent from Filter.									
26.18	-	9.27	-	.0580	0.1312	-	-	1.94	-

Conclusions.

The experiments and investigations of the Board concerning the treatment of waste liquors from paper mills have shown quite clearly that a satisfactory method of treatment is to allow all the wastes, except perhaps those from the rotary boilers, to run together, and then to pass the liquor through coke or similar strainers at a high rate. The resulting effluent will be quite uniformly of good quality, and the wastes left upon the strainers will contain so much fiber as to be held together like matting and easily removed. At filter plants where mechanical filters and coagulants are used for clarifying the water supply use can be made of the wash water of these filters, inasmuch as they contain more or less chemicals, for partial purification of some of the wastes.

Waste Dye Liquors.

Early in the history of the station the purification of sewage colored with dyestuffs was given considerable attention, and it was found that a large proportion of the coloring matters in the sewages treated was removed by intermittent sand filtration. Long-continued application of colored sewage to a filter, however, lessened its efficiency for removing these colors. In the review of the work upon the purification of tannery wastes it has been mentioned already that intermittent sand filters receiving these wastes, though highly colored oftentimes with dyestuffs, removed practically all of this color.

During 1903 much was done upon methods for decolorizing the dye-house wastes from one of the large Lawrence mills. At this mill about 62,000 gallons of water were used each day in dyeing. The total volume of water used for dyeing and washing, however, averaged about 850,000 gallons per day. Cooling the water, for example, in the dye vats before discharging by adding large volumes of cold water, etc., caused a volume of colored water much larger than the 62,000 gallons actually used in the dye vats to be discharged from the mill. The dyes used varied greatly, but it is probable that anilines and a small amount of wood extracts were the colors contributing most largely to the wastes studied. The liquors were all so highly colored that a half-gallon bottle filled with them would scarcely allow the passage of light. There were all colors, from red to violet, but the predominating hue was blue-black. There was present, furthermore, considerable waste matter in suspension, consisting largely of pieces of yarn, etc.

Filtration of Dye Liquors.

Three filters — intermittent sand, coke contact and trickling — were operated with this waste. Each filter was 5 feet in depth, and the rates were 50,000, 400,000 and 540,000 gallons per acre daily, respectively. These filters were numbered 197, 198 and 199.[1] The sand filter, No. 197, was operated for seven months, produced a clear effluent having a pale yellow color and removed 95 per cent. of the organic matter. Contact Filter No. 198, operated for three months, removed the color less completely, but removed 80 per cent. of the organic matter. The trickling filter of broken stone, operated for three months, reduced the color even less than the contact filter, and removed about 70 per cent. of the organic matter of the wastes applied.

The average analyses of dye liquor and effluents are given in the following table: —

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[1] See pages 271-277, inclusive, report for 1903.

Average Analyses of Dye Liquor and Effluents.

[Parts per 100,000.]

	Appearance.		Ammonia.			Chlorine.	Nitrates.	Oxygen Consumed.
	Sediment.	Odor.	Free.	Total.	In Solution.			
Dye liquor, ...	Decided.	Strong dextrine.	.3285	.2616	.1548	2.68	.00	6.28
Effluent from Filter No. 197,	None.	None.	.0219	.0193	-	-	.29	0.41
Effluent from Filter No. 198,	V. slight.	V. Slight.	.2413	.0672	-	1.89	.04	1.14
Effluent from Filter No. 199,	V. slight.	Slight.	.2608	.1034	-	1.59	.09	1.94

Chemical Precipitation of Dye Liquors.

Many experiments upon the treatment of these wastes by chemical precipitation were made. The wastes treated were all deeply colored red, blue, green, black, etc. With most of them the best results were obtained by adding lime and ferric chloride in varying proportions, the total amount added never being greater than one ton per million gallons treated. By this treatment practically all the coloring matters were often coagulated and removed. Other precipitants, such as copperas, iron, alum, etc., gave at times good results, either singly or in combination with each other or with lime. The amount of precipitant required varied greatly, according to the character of the dye liquors treated, but generally copperas followed by lime in amounts of about one-half a ton each per million gallons of dye liquor caused excellent coagulation and marked removal of color and organic matter.

Filtration of Clear Liquor from Chemical Treatment of Dye Wastes.

Filter No. 205. — This filter contained 4 feet in depth of sand with an effective size of 0.27 millimeter, over the usual underdrains. The filter received supernatant dye liquor from chemical treatment at the rate of 2,000,000 gallons per acre daily. It was operated for six months, and the average analysis of its effluent was as follows: —

[Parts per 100,000.]

Color.	Ammonia.		Nitrates.	Oxygen Consumed.
	Free.	Albuminoid.		
Pale yellow, ...	.3733	.0931	.12	1.54

Filter No. 214. — This filter was constructed of 4 feet in depth of soft coal ashes. It received supernatant dye liquor from chemical treatment at a rate of 2,000,000 gallons per acre daily. Its average analysis was as follows: —

[Parts per 100,000.]

Color.	Ammonia.		Nitrates.	Oxygen Consumed.
	Free.	Albuminoid.		
Light yellow, ...	.5000	.1047	.03	1.35

Treatment of Sludge on Ashes.

Filter No. 206. — This filter was constructed of 2 feet in depth of soft coal ashes. It received the sludge from chemical treatment of the dye liquor at a rate of 40,000 gallons per acre daily. The applied liquor generally disappeared in twenty-four hours, so that the filter was ready to receive the next day's application. When the period required for disappearance became unduly great, it was necessary to remove the sludge, and this was done four times in five months. The effluent from the filter was always clear and colorless, and it contained an exceptionally small amount of the organic matter, as the following average analysis shows: —

Average Analysis of Effluent from Filter No. 206.

[Parts per 100,000.]

Turbidity.	Color.	Ammonia.		Nitrogen as —		Oxygen Consumed.
		Free.	Albuminoid.	Nitrates.	Nitrites.	
None.	.05	.0352	.0104	.17	.0001	.10

Table showing Average Percentage Removal of Organic Matter from Dye Liquor by Various Treatments.

	Per Cent. Removed.	
	Albuminoid Ammonia.	Oxygen Consumed.
Chemical treatment: —		
Two hours' sedimentation, ...	21.3	55.9
Sixteen hours' sedimentation, ...	46.0	64.0
Effluent from Filter No. 205, ...	78.0	88.0
Effluent from Filter No. 197, ...	94.0	96.0

WASTE LIQUORS FROM CREAMERIES.

Experiments were made during 1898–99 upon methods for purifying the waste from creameries. This waste consisted largely of the water used in washing out cans, churns and other utensils, together with the milk washed from these cans. There was, of course, a very large amount of putrescible organic matter in this waste. A sample from a creamery, supposed to represent the strongest waste liquor from that place, was collected and analyzed, with the following results: —

Creamery Waste.

[Parts per 100,000.]

Solids.			Ammonia.				Oxygen Consumed.
			Free.	Albuminoid.			
Total.	Loss on Ignition.	Fixed.		Total.	In Solution.	In Suspension.	
145.0	130.7	14.3	.2120	4.62	0.72	3.90	51.20

Owing to the difficulty in obtaining samples representing the entire wastes from the creamery, it was thought that experiments with mixtures of milk and water in different proportions could be made at the experiment station, and that the results could be applied in the purification of the wastes from the creamery. The first experiment was as follows: —

A filter containing 4 feet in depth of clean sand of an effective size of 0.23 millimeter was put into operation on April 11, 1898, and received a mixture containing at first equal proportions of skimmed milk and water at the rate of 200,000 gallons per acre daily. The strength of this mixture was so great that it was applied to the filter for two days only. On the third day the rate was reduced to 100,000 gallons per acre daily, and the liquor applied contained one-third skimmed milk to two-thirds water. Even this mixture clogged the filter badly, and on April 22, 2 inches of curd were removed from its surface and the filter was dug over to a depth of 6 inches. After this the liquor applied to the filter contained only one thirty-fifth as much milk as water, and its analysis was as follows: —

Applied Liquor.

[Parts per 100,000.]

Ammonia.		Oxygen Consumed.	Bacteria per Cubic Centimeter.
Free.	Albuminoid.		
1.65	7.67	42.50	16,000,000

The amount of ammonia found in the mixtures of milk and water and also the amount of oxygen consumed from permanganate, varied with different samples of milk and with the same sample at different ages. The skimmed milk used at first was generally sour when applied to the filter, and the reaction of both the liquor applied and of the effluent was acid. No nitrification took place in the filter during this period, and the average analysis of the effluent for each of the two following months was as follows: —

Effluent.

[Parts per 100,000.]

Month.	Ammonia.		Nitrogen as —		Oxygen Consumed.	Bacteria per Cubic Centimeter.
	Free.	Albuminoid.	Nitrates.	Nitrites.		
1898.						
April, ...	5.20	18.50	.00	.0080	217.00	23,000,000
May, ...	15.23	2.72	.00	.0040	5.33	36,000,000

Beginning June 1 the mixture of milk and water was sweet at the time of application at least half the time, and, when sour, milk of lime was added in amounts varying from 1 to 13 grains per gallon, to make the liquor slightly alkaline. The effluent from the filter did not improve, however, and continued to have a strong odor of sour milk and an acid reaction. After this for two weeks the filter was flooded with water daily, the rate being the same as that with the mixture of milk and water. At the end of this period the filter was again in good condition and the liquor was applied once more. The effluent improved slightly from this time on, and nitrification was at times active. This activity continued for a large part of the next two months, but at times the results were still poor. The strength of the applied liquor was, therefore, still further reduced, so as to contain less than 1 per cent. of milk, whereupon good nitrification began again in the filter.

The effluent from the filter during the first months of operation had the odor of sour milk, and this odor persisted until the end of October. As nitrification became fairly constant in the filter, the odor of the effluent became much less marked, and with the advent of colder weather it was distinctly less noticeable; and during 1899 the effluent was clear, practically colorless and without a distinguishing odor.

At the end of 1898 the rate of operation of the filter was reduced to 50,000 gallons per acre daily. The average analysis of the liquor applied to and of the effluent from the filter during the last three weeks of December, 1898, and the first week of January, 1899, was as follows: —

[Parts per 100,000.]

	Ammonia.		Nitrogen as —		Oxygen Consumed.	Bacteria per Cubic Centimeter.
	Free.	Albuminoid.	Nitrates.	Nitrites.		
Applied liquor,	.10	2.2500	-	-	9.15	-
Effluent,	.80	0.0750	2.70	.0500	0.38	77,000

On Jan. 7, 1899, the strength of the applied liquor was practically doubled, but the rate of application was reduced to 25,000 gallons per acre daily. The average analysis of the applied liquor during this period was about the same as that of the sample obtained from the creamery previously mentioned. The filter (No. 106) was continued in operation up to the end of November, 1899. Beginning in June, water at the boiling point was mixed with the milk, and it was still at about 100° F. when applied to the filter. This method was pursued because, at the creameries, the cans, churns, etc., were washed with boiling water. It was desired to ascertain not only what effect this treatment of the milk as washed from the utensils would have upon its purification by the bacteria in the filter, but also the effect of high temperatures upon the surface of the filter. Upon July 10 salt was added to the creamery waste applied to the filter thereby increasing the chlorine present to over 500 parts. This was done because considerable ice cream was made at the creamery during the summer months, and, consequently, the waste contained a large amount of salt. Nitrification within the filter was not seriously disturbed by any of these changes, however, although the amount of free and albuminoid ammonia in the effluent increased slightly. The filter continued to purify the waste successfully, as is shown by the following table, which gives the average analysis of the liquor applied to and of the effluent from the filter during the latter part of 1899: —

Creamery Wastes applied to Filter No. 106.

[Parts per 100,000.]

Quantity Applied. — Gallons per Acre Daily.	Temperature (Degrees F.).	Ammonia.		Chlorine.	Nitrogen as —		Oxygen Consumed.	Bacteria per Cubic Centimeter.
		Free.	Albuminoid.		Nitrates.	Nitrites.		
26,400	54	.2764	4.9800	208.00	-	-	35.82	-
Effluent from Filter No. 106.								
-	61	.5665	0.0969	214.85	6.61	.1594	0.68	46,400

The experiments with creamery wastes are described in the report of the Board for 1898, pp. 466–472, inclusive; and in the report for 1899, pp. 466–468, inclusive.

Binder's Board Wastes.

A filter (No. 310) was put into operation at Lawrence to which was applied the waste water from a mill making binder's board from old paper and clay. The waste was very foul, contained much heavy suspended matter and the daily volume discharged from the plant was from 250,000 to 300,000 gallons. The waste was generally colored brown, and the suspended matter settled readily. The supernatant waste after sedimentation was applied at the rate of 200,000 gallons per acre daily to a filter containing 4 feet in depth of sand of an effective size of 0.25 millimeter. The waste putrefied quickly, but the effluent from the filter was non-putrescible, fairly clear and practically odorless. Average analyses of the entire waste, of the supernatant liquor applied to and of the effluent from the filter follow. These analyses show that the filter removed 50, 82 and 81 per cent. of the organic matter in the applied waste, as shown by loss on ignition, albuminoid ammonia and oxygen consumed determinations, respectively.

Filter No. 310.

Waste.	Total Residue.	Loss on Ignition.	Ammonia.		Nitrogen as —		Oxygen Consumed.
			Free.	Albuminoid.	Nitrates.	Nitrites.	
Raw,	67.9	29.4	.1800	.3550	-	-	7.20
Applied,	32.1	16.0	.1197	.1930	-	-	3.72
Effluent,	24.9	7.9	.0102	.0355	.11	.0002	0.70
Percentage removal: —							
By sedimentation,	53	46	33	46	-	-	48
By sedimentation and filtration.	63	73	94	90	-	-	90
By filtration,	22	50	91	82	-	-	81

Yeast Wastes.

The fact that the wastes from a yeast works greatly impaired the efficiency of a sewage-disposal area led to investigations as regards the processes carried on in making this product, and to experiments upon the waste liquors resulting therefrom. The output of the plant was approximately 50,000 pounds of yeast per month, together with comparatively small quantities of white vinegar. The total daily volume of actual wastes was approximately 16,000 gallons.

The raw stock used at the works consisted of molasses and barley malt. The molasses, diluted with town water, was mixed in certain proportions with a mash of barley malt and water, the combined mixture being stirred and heated in a tank, from which it was then drawn off into a so-called fermenting tank. After the process of fermentation, during which the liquor was cooled and the yeast settled out, most of the supernatant liquor was drawn off and was either discharged directly into the sewer by gravity or pumped into a still and used in the manufacture of vinegar. This liquor, which was called "beer," was pumped into the still during less than two days per week. It was wasted at other times because of insufficient apparatus to handle more than two days' supply. The distillate was stored in tanks and was subsequently filtered through wooden or rattan shavings, during which process it became aerated and changed from a crude form of whiskey into white vinegar. The heavy residue in the still, amounting approximately to 2,500 gallons, was discharged gradually during the process of distillation directly into the sewer. On the days when vinegar was made, the still was usually in operation for a period of from eight to twelve hours.

The yeast which settled out in the fermenting tank, together with what was left of the beer, was pumped into two washers, where it was diluted with water and allowed to stand. After the yeast settled out the supernatant liquor, including some of the beer, so called, was discharged into a cistern in the rear of the building. This waste water was called the "primary wash." More water was then added to the yeast, and, after another period of settling, the supernatant liquor or wash water, so called, was discharged into the cistern. The yeast was usually washed in this manner at least five times, — never more than six times, it was claimed.

The only other waste waters resulting from the manufacture of the yeast consisted of (1) water containing small amounts of lime which had been used in washing out the tanks, (2) press liquor and water used in washing the press cloths, (3) floor washings, and (4) cooling water. In addition to the various liquid wastes, there was a small quantity of dry residue from the tank in which the barley malt mash was prepared. This was sold to farmers for 5 cents a bushel. All of the liquid wastes, with the exception of the "beer," the concentrated liquor from the vinegar still and the cooling water, entered the cistern; the "beer" and concentrated liquor were discharged into the sewer and the cooling water into the swamp east of the factory. The quantity of the various wastes was as follows: —

	Gallons per Day.
Yeast liquor ("beer"),	3,500
Heavy residue in vinegar still,[1]	2,500
Primary wash,	1,500
First wash,	2,200
Second wash,	2,200
Third wash,	2,200
Fourth wash,	2,200
Fifth wash,	2,200
Total,	18,500

In November, 1908, samples of two classes of waste were collected frequently and sent to the experiment station for analysis, and several small filters were started with mixtures of these wastes. Neither the wastes from the still nor those from the yeast washings were of a putrescible character, and that difficulty would be encountered in bacterial purification of such liquids was thus foreshadowed.

Three filters were put into operation, two of them containing 3½ feet in depth of sand of an effective size of 0.25 millimeter and the other containing practically the same depth of clinker. The first filter (No. 359) was operated at the rate of 25,000 gallons per acre daily, and at first received the wastes mixed in equal proportions, but after November 16 the proportion was 1 part of still liquor to 2 parts of yeast washings, and the rate was increased to 50,000 gallons per acre daily. Soon after starting this filter the wastes became acid on standing, and were made alkaline with lime before application to the filter. This filter was operated for four months, but, with the exception of some slight nitrification at first, its only action was practically that of a strainer. By the straining action about 50 per cent. of the organic matter was removed from the applied waste.

The second filter (No. 364) was started at a rate of 50,000 gallons per acre daily, and received a mixture of 95 per cent. Lawrence sewage and 5 per cent. of the mixed waste from the yeast factory. After two months' operation the percentage of waste in the mixture was increased to 7½

[1] Once or twice a week.

per cent. This waste was neutralized with lime for a time, but after February 13 this addition of lime was omitted. After about six weeks' operation the filter began to nitrify well and the nitrates increased from time to time. Attempts to increase in the applied liquor the proportion of waste from the factory above that stated were followed on each occasion by a very great reduction in the nitrification. The filter containing 3 feet in depth of clinker accomplished practically no purification. In a sand filter to which this waste was applied after mixture with septic sewage sludge, and after a long period of rotting, nitrification did not occur, although 50 per cent. of its organic matter was removed.

The average analyses of the two classes of wastes as taken at the factory, of the waste applied to and of the effluents from the filters described above follow: —

Average Analyses.

Outlet of First Tank or Still.

[Parts per 100,000.]

Solids.			Ammonia.			Kjeldahl Nitrogen.	Nitrogen as —		Oxygen Consumed.	Bacteria per Cubic Centimeter.
				Albuminoid.						
Total.	Loss on Ignition.	Fixed.	Free.	Total.	In Solution.		Nitrates.	Nitrites.		
3199.0	2462.5	736.5	4.37	30.63	28.43	49.83	-	-	800.7	-
Yeast Washings.										
775.4	650.4	125.0	1.18	6.42	5.15	9.88	-	-	142.0	-
Waste Liquor applied to Filter No. 359.										
-	-	-	1.89	12.40	-	-	-	-	352.1	30,010,000
Effluent from Filter No. 359.										
-	-	-	1.89	6.46	-	-	0.24	.0213	150.0	4,133,500
Waste Liquor applied to Filter No. 364.										
-	-	-	3.70	1.14	-	-	-	-	19.4	1,656,600
Effluent from Filter No. 364.										
-	-	-	0.72	0.19	-	-	1.41	.0009	2.46	169,679

From further experiments made at Lawrence with these wastes it was determined that, by a period of sedimentation of two hours, about 25 per cent. of the organic matter present in this waste settled out, and that this amount was increased little, if any, by longer periods of sedimentation; that by sand filtration, or by straining of the supernatant waste after sedimentation at a rate of 100,000 gallons per acre daily, between 40 and 50 per cent. of the remaining organic matter could probably be removed. This was shown by means of a small sand filter (No. 379) constructed of 3½ feet in depth of sand of an effective size of 0.26 millimeter. The average analysis of the waste applied to and of the effluent from this filter follow: —

Waste Liquor applied to Filter No. 379.

[Parts per 100,000.]

Free Ammonia.	Albuminoid Ammonia.	Oxygen Consumed.
1.30	7.80	134.00

Effluent from Filter No. 379.

Free Ammonia.	Albuminoid Ammonia.	Oxygen Consumed.
0.70	2.90	85.00

Wastes from a Cotton Batting Factory.

The product of this company consisted of cotton batting and various grades of cotton cloth as well as gauze and surgeons' supplies. The stock used was raw cotton and cotton cloth as it came from the manufacturer, and the processes carried on at the mill consisted largely of washing, bleaching and dyeing. The various processes were found to be somewhat as follows: the cloth or cotton was first boiled in large iron kettles with small amounts of ammonium hydrate, after which it was thoroughly washed, there being usually two distinct washings. After these washings the goods were bleached with chloride of lime and were again thoroughly washed. The stock was then soaked in an acid bath to neutralize any of the bleaching solution which might have remained in the cloth, and was again washed two or three times. It was finally boiled for a second time with soap, and then washed again two or three times, depending on whether the stock consisted of cloth or cotton. The cotton stock was usually given a second acid bath after the second boiling just referred to, and was then washed three or four times to make sure that no acid was left in the goods. In addition, some dyeing was done, but this portion of the work was carried on at irregular intervals, and the amount of stock so treated was small. Liquid wastes resulted from practically all of the processes, and the wash waters and spent dye solutions were discharged directly into the river. The total daily amount of wastes discharged amounted approximately to 50,000 gallons. The worst wastes to be discharged directly into the stream were the water used in boiling the stock with ammonium hydrate and that used in boiling the stock for a second time with soap. Measurements of the daily quantity of these wastes, made in 1908, were as follows: —

	Gallons.
Water in which stock had been boiled with ammonium hydrate, . .	3,800
Water in which stock had been washed after being boiled, . . .	7,600
Spent bleaching solution, ...	1,000
Water used in washing stock after it had been bleached, . . .	9,000
Spent acid solution, ...	1,000
Wash waters used after acid bath, ...	9,000
Water in which stock was boiled for a second time with soap, . .	4,000
Water used in washing stock after second boil, ...	9,000
Acid bath used on cotton stock, ...	500
Wash water used after second acid bath on cotton stock, . . .	6,000
Total, ...	50,900

Spent dye liquors and wash waters amounted to from 5,000 to 10,000 gallons per day.

During 1906 samples of the wastes were collected at the mill and sent to the experiment station. The strongest of the wastes (the first and second boiling of the stock) were mixed and applied to a filter (No. 311) constructed of 3 feet in depth of sand of an effective size of 0.25 millimeter, at a rate of 50,000 gallons per acre daily. On several occasions mixtures of all the wastes were applied to this filter. By the mixture of the strong wastes considerable soap was generally precipitated, and a fairly clear, supernatant liquor obtained. When the filter was operated with a mixture of the two strongest wastes, and with a mixture of all the wastes, the effluent from the filter was clear, colorless and non-putrescible, and the filter removed 73, 89 and 91 per cent. of the organic matter in the applied waste, as shown by loss on ignition, albuminoid ammonia and oxygen consumed results, respectively. The average analysis of the waste as received, of the waste applied to and of the effluent from the filter follow: —

Waste.	Total Residue.	Total Loss on Ignition.	Ammonia.		Nitrogen as —		Oxygen Consumed.
			Free.	Albuminoid.	Nitrates.	Nitrates.	
Raw, ...	292.6	69.6	.1887	.6835	–	–	10.85
Applied, . . .	249.4	54.8	.1210	.5660	–	–	8.85
Effluent, . . .	182.1	14.8	.0334	.0614	.04	.0046	0.84
Percentage removal, .	27	73	72	89	–	–	91

The experiments indicated that the wastes being discharged into the river could be satisfactorily purified after sedimentation by filtration through sand at a rate of 50,000 gallons per acre daily.

Wastes from Silk Mills.

Experiments were made also upon the disposal and purification of the waste liquors from a silk mill. The daily volume of sewage or waste liquor from this mill approximated 2,500,000 gallons. This liquor varied much in character at different periods of the day on account of the varying processes carried on in the mill, at one time resembling in appearance domestic sewage and then quickly changing to a bright blue, pink, crimson or other color, due to the discharge of waste dye liquors. In fact, these dye liquors colored the sewage oftentimes to such an extent that it became nearly as highly colored as the dyes in the dye vats.

Besides this coloring matter, a very large assortment of chemicals, etc., was used daily in the mill, a list too long to be given here; but as examples a few are mentioned below, together with the average amount of each used daily: —

	Pounds.
Carbonate of soda,	124
Silicate of soda,	147
Ammonia,	52
Sulphuric acid,	173
Acetic acid,	181
Nitrate of iron,	339
Bichloride of tin,	237
Sulphate of alumina,	60
Sodium phosphate,	235
Glauber's salt,	88
Chloride of lime,	186
Logwood,	80
Dextrine,	1,307
Vegetable gum,	91
Aniline dyes,	156
Soap,	2,000
Muriatic acid,	115
Silk gum, etc., worked off the raw silk and entering the sewage,	1,520

The list prepared by the mill people contained approximately fifty different substances.

Experiments showed that the surfaces of sand filters became clogged quite quickly when this liquor was applied to them, a result due chiefly to the starch, dextrine, soap, silk gum, etc., in the sewage. Experiments were therefore made to find methods of preliminary treatment of the sewage before applying it to the sand filters. Three methods were tried, namely, a septic tank, a coke strainer and a contact filter. After a preliminary experiment, which showed that the clogging matters could be removed by each of these processes, good-sized experimental tanks and filters were put into operation at the mill.

The septic tank and accompanying sand filter were of such size and capacity that the sewage applied to the septic tank took twenty-four hours to pass through, and the rate attained by the sand filter which received this sewage was 200,000 gallons per acre daily. The coke strainer was operated at first at the rate of 1,200,000 gallons per acre daily, and the contact filter at the rate of 1,350,000 gallons per acre daily, these rates being nearly doubled afterwards. The rates of the sand filters receiving the sewage from the coke strainer and from the contact filter varied from 150,000 to 225,000 gallons per acre daily.

These experiments showed that the coke strainer was the most efficient in removing the clogging matters from the silk liquor, that is, it removed nearly 75 per cent. of these matters; the septic tank removed 50 per cent. and the contact filter about 40 per cent. In each case the resulting liquor was in good condition for purification by sand filtration at the rate stated. Active nitrification in the filters ensued, and their effluents in each instance were generally quite low in color, notwithstanding the bright colors at times of the sewage applied. In spite of the large amount and variety of chemicals allowed to run to waste from the silk mill, the sewage was never sterile, but contained generally at least 3,000,000 bacteria per cubic centimeter.

Wastes from the Manufacture of Illuminating Gas.

Experiments were made also upon the purification of the wastes resulting from the manufacture of both coal and water gas. Taken as a whole, the waste liquor was a very turbid, brownish-black fluid, containing considerable floating oily matter saturated with carbonaceous matters in solution, — hydrocarbons, — and having a heavy sediment of tar. It was soon evident that chemical treatment would be necessary before filtration. Many experiments with both lime and copperas as precipitants were made on the entire mixed liquor, and also on the separate wastes from the water-gas plant and the coal-gas plant. Chemical treatment was successful in coagulating and removing by sedimentation a large percentage of the suspended and dissolved matters in these wastes. Lime at the rate of a ton and one-half per million gallons was effective generally with the wastes from the water-gas plant, but with the wastes from the coal-gas plant more certain results were obtained when copperas was used in combination with lime, in amounts averaging about a ton to each million gallons of liquor treated. The solid matters in the untreated liquor varied at times from 3,000 to 52,000 parts per 100,000 a large percentage of which was loss on ignition. The total solid matters after chemical treatment were generally less than 100 parts, with from 20 to 40 parts loss on ignition.

The volume of wastes from the process of making water gas varied from 5,000 to 25,000 gallons per day, while the volume of wastes from the coal-gas plant was much less in amount.

A filter containing a mixture of sand and coke, was operated at this plant for several months, taking all the supernatant liquor after treating the entire water-gas wastes with lime, sedimentation and coke straining. The time required for chemical precipitation and sedimentation was generally but little over an hour. The coke strainers were but a few feet square, placed in walls, dividing sections of the settling tank. The filter was operated at rates from 500,000 to 2,000,000 gallons per acre daily, and although the latter rate was too great to allow much change in the liquor, still many of the odors were removed while it passed through the filter. The resultant liquor was generally fairly clear, with little odor and with total solids and loss upon ignition low.

The experiments indicated that there should be but little difficulty in purifying these gas wastes sufficiently by chemical precipitation and rapid filtration or straining. Filtration after chemical treatment at rates up to 700,000 or 800,000 gallons per acre daily should produce a clear liquor with little odor and but a small percentage of the original polluting matters. Aeration of this liquor before filtration aids materially the removal of odors.

Wastes from a Finishing Company.

The wastes from the mill of this company came from the processes used in the bleaching and dyeing of cotton cloth and in the dyeing of skein yarn. Khaki was treated to a considerable extent and also some heavy duck cloth. The volume of wastes from the bleachery, or old part of the mill, figured from the measurements taken during the summer of 1909, was about 140,000 gallons per day of ten hours, although this amount was apt to vary considerably. The wastes included lime-boil liquor, soapy solutions, dirty rinse waters, some acid wastes and rinse dye liquor. During a large part of the year, when the water in the stream was low, the wastes from the mill gave it an extremely dirty appearance. Under normal conditions the output of the bleachery was about 40,000 yards of cloth per day.

A new building was erected in the spring of 1909 for the dyeing of skein yarn and raw cotton. Soon after, this part of the mill was put into operation, and samples and measurements were taken of the wastes, which consisted of spent dyes and wash waters. Between 80 and 90 per cent. of these wastes was rinse water and was not very objectionable. The wastes from this part of the mill varied considerably in amount from day to day, depending upon the condition of business. During the summer of 1909 separate systems of piping were laid under the new building for the separation of the objectionable wastes from the rinse waters. The total quantity of wastes from this part of the mill when the measurements were taken amounted to about 500,000 gallons per day of ten hours, but several changes made since that time have tended to decrease the discharge. At the time investigations were made at the plant this department of the factory was shut down.

Frequent examinations were made at the mill during the summer of 1909, and samples were collected from the bleachery, or older portion. These samples were taken from the various machines, and were representative, so far as possible, of the waste liquor entering the brook. For about four and one-half months samples of the wastes from this mill were shipped to the experiment station for analysis. The wastes as received were, in a general way, non-putrescible, very turbid and contained a large amount of flocculent precipitate. The supernatant liquor resulting from the settling of this precipitate was applied from May 29 to September 22 to a filter (No. 374) constructed of 4½ feet in depth of sand of an effective size of 0.26 millimeter, at a rate of 50,000 gallons per acre daily. The effluent from the filter was invariably clear, colorless and non-putrescible, and contained but a small part of the organic matter in the applied waste.

The following table gives the analysis of the waste as received at the station, of the supernatant waste applied to and of the effluent from this filter. It will be seen that the effluent from the filter contained only about 11 per cent. of the original organic matter in the waste, as shown by the albuminoid ammonia determinations, and about 15 per cent. of the amount in the waste applied. The removal of carbonaceous organic matter, as shown by the oxygen consumed determinations, was very great, the effluent from the filter containing only about 4 per cent. of that in the waste as received, and 10 per cent. of that in the waste as applied to the filter. The filter was in good condition at the end of the experiment and it was evident that this waste could be efficiently purified by settling tanks and sand filters.

Average Analysis of Waste as Received.

[Parts per 100,000.]

Solids.			Color.	Ammonia.			Nitrogen as —		Oxygen Consumed.
				Free.	Albuminoid.				
Total.	Loss on Ignition.	Fixed.			Total.	In Solution.	Nitrates.	Nitrites.	
338.0	142.7	195.3	-	.3452	.6727	.5055	-	-	42.57

Average Analysis of Waste applied to Filter No. 374.

247.4	99.3	148.1	-	.1275	.4517	.3063	-	-	21.83

Average Analysis of Effluent from Filter No. 374.

-	-	-	.79	.1850	.0891	-	.02	.0002	2.12

Waste Liquors from Dyeing, Bleaching and Mercerizing Cotton Yarn.

Upon investigation at the plant where these processes were carried on it was found that the total amount of waste water discharged was about 60,000 gallons per twenty-four hours. Of this total, about 25,000 gallons represented the worst of the wastes, namely, (1) water in which the yarn was boiled with soda ash; (2) spent heavy dye liquor; (3) heavy rinse water from dyeing; (4) hot rinse water after mercerizing; (5) hot soap bath after bleaching; and (6) cold rinse after the soap bath. A composite waste, representing a combination of these six wastes in the right proportions, was used in the experiments. Two filters (Nos. 318 and 319) were put into operation at the station and to them the average waste was applied. Each filter contained 3 feet in depth of sand of an effective size of 0.25 millimeter and was operated at the rate of 50,000 gallons per acre daily, Filter No. 318 receiving the supernatant waste after sedimentation and Filter No. 319 the supernatant waste after treatment with chemical precipitants. The average waste was brown in color, very turbid, and but a small portion of the matters in suspension settled readily. The effluent from Filter No. 318 was straw-colored and had but slight odor. This filter removed 56, 87 and 90 per cent. of the organic matter in the applied waste, as shown by loss on ignition, albuminoid ammonia and oxygen consumed determinations, respectively. The effluent from Filter No. 319 was of slightly better quality than that from Filter No. 318, Filter No. 319 removing 69, 87, and 89 per cent., respectively, of the organic matter in the applied waste, as shown by the determinations just mentioned.

The average analyses of the raw waste, of the waste applied to and of the effluents from these filters follow: —

Filter No. 318.

Waste.	Total Residue.	Total Loss on Ignition.	Ammonia.		Nitrogen as —		Oxygen Consumed.
			Free.	Albuminoid.	Nitrates.	Nitrites.	
Raw, ...	453.2	101.7	.1450	1.4900	-	-	32.30
Applied, ...	456.8	104.3	.2050	1.5300	-	-	33.10
Effluent, ...	332.4	45.5	.1016	0.2037	.02	.0198	3.45
Percentage removal: —							
By filtration, . . .	27	56	50	87	-	-	90

Filter No. 319.

Waste.	Total Residue.	Total Loss on Ignition.	Ammonia. Free.	Ammonia. Albuminoid.	Nitrogen as — Nitrates.	Nitrogen as — Nitrites.	Oxygen Consumed.
Raw, ...	506.8	64.6	.0900	0.9200	-	-	18.40
Applied, ...	503.6	49.4	.1900	0.6200	-	-	1.60
Effluent, ...	365.1	15.5	.0540	.0807	.07	.0017	1.27
Percentage removal: —							
By precipitation, . .	1	24	-	33	-	-	37
By precipitation and filtration.	28	76	40	92	-	-	93
By filtration, . . .	28	69	72	87	-	-	89

Shoddy Mill Wastes.

During 1906 experiments were made upon wastes from a mill manufacturing goods from rags. From 60,000 to 70,000 gallons of waste liquor were discharged from this mill daily. Processes for carbonizing, washing and dyeing rags were carried on at the plant, and the wastes discharged were those resulting from washing the rags after carbonizing, and also the spent dye liquor from dyeing. Hematine dyes were used, and as the amount of dyeing at the mill during this year was comparatively small, the wastes from this process were insignificant. The carbonizing process consisted in treating the rags with a solution of sulphuric acid. The waste water and the wash water from washing the rags after carbonizing were dirty and contained a considerable amount of sulphuric acid. From 250 to 1,200 pounds of lime per million gallons of waste were required to neutralize it, or about 20 to 100 pounds for the volume of waste discharged. The waste as received at the station contained considerable heavy black sediment, but the supernatant liquor was fairly clear, and the addition of lime caused still further clarification. The supernatant waste after neutralization was applied for two months to a filter (No. 302) containing 3 feet in depth of sand of an effective size of 0.28 millimeter, at a rate of 100,000 gallons per acre daily. The effluent from this filter was clear, colorless, non-putrescible, and nitrification was active. The average analyses of the waste as received, as applied to the filter and of the effluent from the filter are given below, and it will be seen that by sedimentation and filtration 75, 88 and 85 per cent. of the organic matter in the applied waste, as shown by loss on ignition, albuminoid ammonia and oxygen consumed determinations, respectively, was removed: —

Filter No. 302.

Waste.	Total Residue.	Total Loss on Ignition.	Ammonia.		Nitrogen as —		Oxygen Consumed.
			Free.	Albuminoid.	Nitrates.	Nitrites.	
Raw,	71.7	36.9	.6400	.4300	-	-	4.39
Applied,	53.6	10.1	.6225	.1298	-	-	1.94
Effluent,	61.1	9.4	.0176	.0534	1.01	.0419	0.67
Percentage removal: —							
By sedimentation,	25	72	3	70	-	-	56
By sedimentation and filtration.	15	75	97	88	-	-	85
By filtration,	-	7	97	59	-	-	65

In 1908 further experiments were carried on with the wastes from this mill, as it was said that the process by which the stock was treated in order to remove cotton, etc., had been changed. In removing the cotton two processes were employed at this time; the greater part of the rags, however, were treated as follows: the rags sorted as to color were torn into small pieces and soaked in a bath of cold sulphuric acid for about three hours. The strength of this bath varied from 6 to 9° Beaumé for different kinds of cloth; that is, the bath contained 7 to 10 per cent. sulphuric acid. The rags were then removed, drained and partly dried in a centrifugal drier. The drying was finished in steam-heated vats at about 200° Fahrenheit, the cotton present being carbonized by this process. The driers were not ventilated and the moisture was condensed on pipes in which cold water circulated. When dry, the cloth was taken to dusters, by which the carbonized cotton was separated from the wool as a fine dust, to be drawn off by a suction fan and deposited near the boiler room where it was burned. After this the cloth was washed from fifteen to twenty minutes in a machine like a paper-machine washer, and carbonate of soda was stated to be added in quantities sufficient to neutralize the acid. Other rags were treated by a process in which a warm ammonium chloride bath was used instead of a bath of sulphuric acid. The rest of this second process was practically the same as that just described, except that the washing was done without the addition of sodium carbonate. Only a small amount of the stock underwent this second treatment, however, when it was desired to keep a black color.

The wastes were supposed to be neutral or slightly alkaline on account of the addition of sodium carbonate, but it was soon evident that the waste when discharged was still generally acid. The waste as it came from the mill contained a small amount of matter in suspension, which settled very rapidly, leaving a clear liquor. This clear liquor was passed through a sand filter at the experiment station, first at the rate of 100,000 gallons per acre daily and later at a rate of 150,000 gallons per acre daily, with a satisfactory, well-nitrified effluent as a result. Before application to the filter the acid wastes were neutralized by the addition of lime in order to ensure good purification.

The following table presents the average analysis of the waste as it came from the works, after clarification by sedimentation, and of the effluent from the filter: —

Average Analysis of Raw Waste, Waste applied to and Effluent from Filter.

[Parts per 100,000.]

	Color.	Ammonia.		Chlorine.	Nitrogen as —		Oxygen Consumed.	Hardness.
		Free.	Albuminoid.		Nitrates.	Nitrites.		
Raw waste,	–	.9483	.4087	–	–	–	3.05	–
Applied waste,	–	.8000	.1280	3.15	–	–	1.02	12.95
Effluent,	0.23	.0836	.0592	3.93	1.28	.0022	0.79	1.45

Glue Wastes.

Experiments were made during 1908 and 1909 upon the wastes from a glue factory. The stock used at this plant was of three kinds, consisting of two grades of salt stock (fish skins, heads and bones) and fresh fish heads. All three grades were washed before use. After being washed, the best grade of salt stock was cooked in open kettles, while the poorer grade of salt stock and the fresh stock was heated with live steam in closed iron digesters. The results of the cooking in each case consisted of glue liquor and a solid residue. The glue liquor was evaporated and treated in various ways to form the finished product, while the solid residue was pressed and dried, being shipped finally in bags to fertilizer manufacturers. The liquid wastes resulting from the various processes amounted to about 120,000 gallons a day, divided as follows: (1) from skin washers; (2) from fresh fish cookers; (3) from salt fish cookers; (4) floor washings; (5) condenser water; (6) purifiers; and (7) the domestic sewage from 115 operatives. The main sewer of the factory received all this waste at various points and discharged it into a brook below the storage basin of the plant for condenser water. These wastes were putrescent and had strong and offensive odors.

Two filters (Nos. 368 and 370) were operated at Lawrence with the waste. Filter No. 368 was constructed of 4 feet in depth of sand of an effective size of 0.25 millimeter, and received the mixed strong wastes at a rate of 25,000 gallons per acre daily at first and later at a rate of 50,000 gallons per acre daily. The effluent from this filter was always non-putrescible, clear, colorless, odorless, and nitrification was high; but notwithstanding high nitrification the free ammonia in the effluent was also very high, owing to the large amount of nitrogenous bodies present in the applied waste. Filter No. 370 was operated as a trickling filter and was constructed of 6 feet in depth of broken stone of the size most successfully used in trickling filters at the station, and was operated at a rate of 500,000 gallons per acre daily for a month and then at a rate of 750,000 gallons per acre daily. Nitrification began almost immediately in this filter, and the amount of nitrates present was as great as that in the effluent from the sand filter, which was operated at from one-tenth to one-fifteenth as great a rate. The amount of free ammonia present, however, in the effluent from this filter was only one-half as great as in the effluent from the sand filter, this result being due largely, however, to the fact that the wastes obtained from the works were weaker during the period of operation of this filter than during the entire period of operation of the sand filter. The effluent from the trickling filter was practically odorless, stable and of a character equalling in most respects that from trickling filters receiving domestic sewage.

The average analysis of the waste liquor applied to and of the effluents from the two filters follow: —

Average Analysis of Waste Liquor applied to Filters Nos. 368 and 370.

[Parts per 100,000.]

Color.	Ammonia.		Nitrogen as —		Oxygen Consumed.	Bacteria per Cubic Centimeter.
	Free.	Albuminoid.	Nitrates.	Nitrites.		
–	14.22	5.59	–	–	8.77	2,730,000

Effluent from Sand Filter No. 368.

[Parts per 100,009.]

Color.	Ammonia.		Nitrogen as —		Oxygen Consumed.	Bacteria per Cubic Centimeter.
	Free.	Albuminoid.	Nitrates.	Nitrites.		
.36	12.83	0.27	5.25	.4896	0.86	5,000
Effluent from Trickling Filter No. 370.						
.50	6.96	0.66	5.26	.0498	3.15	502,000

Paint Mill Wastes.

Investigations in regard to wastes from a paint factory were made during 1902, 1903 and 1904 as the result of an application in November, 1902, from a local board of health, in which it was stated that much complaint had been made to them concerning the contamination of a lake and connecting brooks by the wastes from certain paint mills. The lake was not a source of water supply, but ice was cut from it in winter and in summer it was used by the students of a girls' college for boating and bathing, the boat-house, bath-house and swimming-float being about 250 yards from the outlet of the brook into the lake. These wastes caused the brook to be badly colored oftentimes. The lake, too, became colored to some extent, and with the wastes a large amount of lead was carried into these waters. Mineral paint, so called, was made, chrome iron ore being the basis. This was mixed with lime or sodium carbonate, or both, and heated, and the sodium chromate formed was passed into solution. This material was then treated in large tanks with lead acetate and sodium bichromate, lead chromate being precipitated, and this yellow body formed the main portion of the paint shipped from the works. Sulphuric acid was added to the tanks at times to vary the shade of yellow formed. Lead acetate was made at the plant by allowing acetic acid to pass over lead. Blue paint was made by treating the lead chromate with Prussian blue, and green paint by mixing the yellow and the blue. A red paint was also made of the lead chromate by treating it with aniline dyes. The only acids said to be used around the works were acetic, nitric and sulphuric. Neither arsenic nor mercury was used. The lead chromate, after being precipitated, was pressed in filter presses and then mixed or ground with oil. No oils were supposed to be allowed to run to waste from the grinding room. Kerosene was used, however, to prevent scale in the boilers, and the exhaust contained some oil which was blown off into the brook.

The lead chromate was precipitated in large tanks, and after sedimentation the supernatant liquor was allowed to run to waste. In the main precipitating room, or "yellow house," there were four tanks which held about 7,000 gallons each, and which were generally emptied once a day, approximately 25,000 to 28,000 gallons of waste liquor passing from them. From the shop in which the blue paint was made practically the same amount of liquor passed into the brook each day, and from the shop in which green paint was made about 2,000 gallons per day. Considerable water was pressed from the precipitate when it was treated in the filter presses, and this waste water was also allowed to run into the brook. It was of course the aim to allow as little color or lead to flow to waste as possible, but there was not sufficient care taken, as was shown by the examinations made.

Samples of the waste from the mill, of the brook and of the lake water were analyzed. Two samples of wastes collected in January, 1903, showed 250 and .03 parts of lead per 100,000, respectively. The analyses of samples of water from the brook when wastes were flowing from the mill and from various parts of the lake itself showed the presence of large amounts of lead. A mixture of various samples of the wastes was made and the amount of lead determined. It was found that about 150 pounds of lead passed from the mill each day in the waste liquors, this amount of lead, according to figures furnished at the mill, meaning a waste of $2,300 worth of lead per year. A sample of ice cut from the lake showed a lead content of .009 part per 100,000. Every acre of water in the lake 1 foot deep contained at the time of this investigation about 2 pounds of lead, making the upper foot of lake water contain about 282 pounds, the lake being 141 acres in area. Deposits in the brook and at the entrance of the brook into the lake also contained large amounts of lead. Experiments upon sedimentation showed that if suitable sedimentation tanks were provided a very large percentage of the lead wasted could be saved and prevented from polluting the lake water, and that the saving of the lead would eliminate the color of the wastes. At the end of 1903 further examinations were made, and samples from the brook showed 3.33 parts of lead per 100,000; a sample collected from the drain entering the brook showed 36.40 parts per 100,000.

As a result of the first investigations the paint company agreed to erect tanks at their works in order to save much of the lead chromate, etc., that was wasted. The mill was visited again in August, 1904, the brook and lake were examined and samples were collected for analysis. It was found at this time that the appearance of the brook was considerably improved; the lake seemed to be free from colored matter, and at the mill, tanks had been erected to save the wastes from that portion of the mill in which green paint was made. Much lead was saved by these tanks and little wasted from them. No provision had been made to save the yellow wastes, a considerable flow of which was passing into the brook at this time. Samples taken from the brook, lake and wastes from the drains discharging yellow lead chromate at this time were collected and analyzed for lead, with the following results: —

[Parts per 100,000.]

Source.	Lead.	Source.	Lead.
Brook, ...	0.0600	Outlet of lake, ...	0.0800
Swimming-pool at the college, . .	0.0800	Yellow wastes from the drains, .	5.6000[1]

[1] 3.4 parts lead in this last waste was in suspension.