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# Wastewater Reuse and Recycle In Petroleum Refineries

**Reuse and recycle techniques in petroleum refineries were effective in reducing wastewater discharges significantly in 12 plants.**

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A study was undertaken to investigate wastewater reuse and recycle techniques in the petroleum refining industry. The objectives of the study were to identify feasible reuse and recycle techniques that can be successful in reducing wastewater discharge and to estimate their associated costs. Site investigations were conducted at 15 petroleum refineries.

The U.S. Environmental Protection Agency (EPA) proposed BAT regulations for the petroleum refining industry in December 1979. Wastewater reduction is a fundamental aspect of the proposed limitations. EPA undertook this study to confirm the cost estimates used in the proposed

guidelines, to identify specific technologies, and to accurately assess their costs. Fifteen refineries were chosen to represent the range of refinery characteristics including crude capacity, processes employed, and wastewater generation. Three of them were selected for their exemplary reuse and recycle techniques which identify technologies already existing in the industry. These technologies were then investigated for their applicability at the remaining 12 facilities. The results of these investigations are presented here, by technology, and include: 1) steam condensate recovery and reuse and vent loss reduction; 2) cooling tower

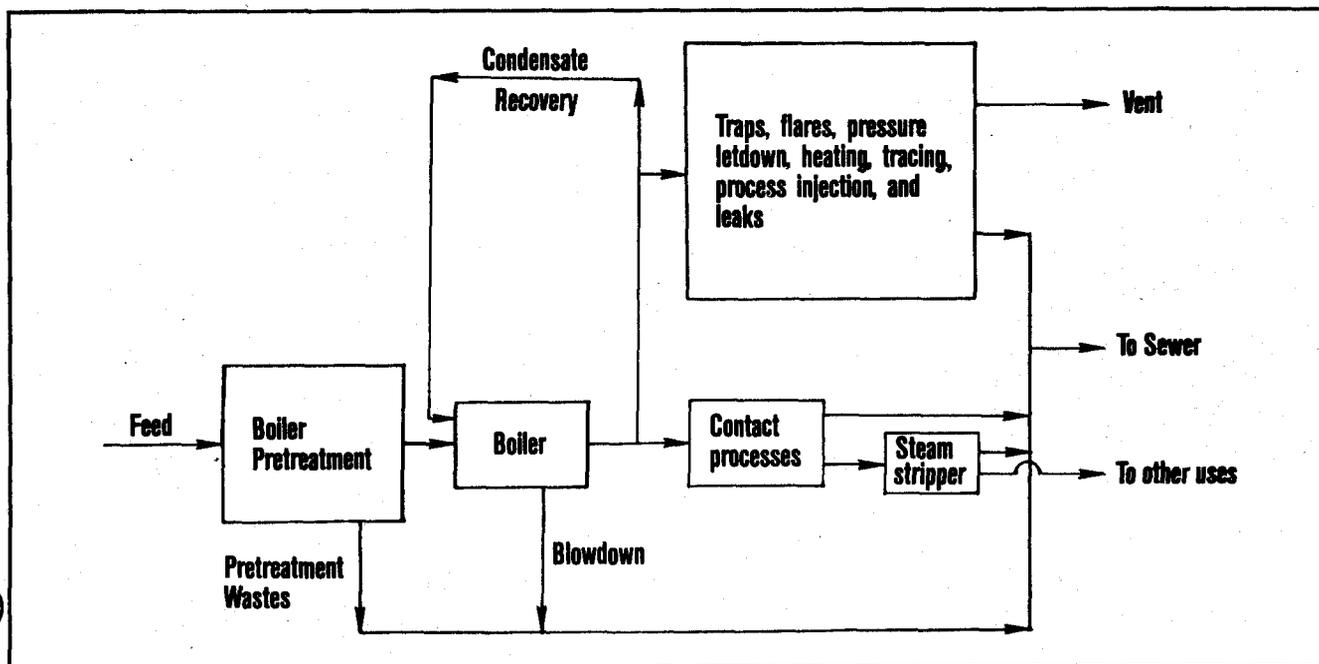


Figure 1. Boiler wastewater sources.

**Table 1. Boiler circuit feedwater before and after optimization.**

Refinery		Boiler Feed, %*				
		To Sewer**	To Recovery	To Vent	To Other***	
1	Before	26	23	51	0	
	After	6	35	56	3	
2	Before	65	0	35	0	
	After	18	76	6	0	
3	No Change	16	58	18	8	CTM = 7, DM = 1
4	Before	49	10	23	18	SPM = 15, DM = 3
	After	22	38	18	22	SPM = 15, DM = 7
5	Before	47	21	24	8	DM
	After	27	44	20	9	DM
6	Before	28	33	36	3	DM
	After	10	47	25	18	DM
7	Before	33	51	16	0	
	After	24	60	16	0	
8	Before	39	51	8	2	DM
	After	23	72	3	2	DM
9	Before	34	55	6	5	DM
	After	25	56	6	13	DM = 5, CTM = 8
10	Before	29	56	8	7	DM
	After	27	59	7	7	DM
11	No Change	43	48	2	7	DM
12	Before	33	47	16	4	DM
	After	30	48	16	6	DM

\*Boiler feed includes recovered condensate and pretreatment system intake of raw water.  
 \*\*Losses to the sewer include pretreatment wastes and backwash, blowdown, and process uses.  
 \*\*\*Other uses include desalter make-up (DM), cooling tower make-up (CTM), and spray pond make-up (SPM).

blowdown control; 3) general process uses; and 4) reuse of treated effluent.

**Condensate recovery and loss elimination**

Refinery boiler systems were studied, since boiler feed volumes are large and since steam is used in many areas of a refinery. The recovery of these large volumes and the resulting energy savings are substantial. Figure 1 presents possible boiler system wastewater sources. The common components of the boiler make-up are recovered condensate and raw water. The common wastewater sources are turbine pressure letdown, heating, cleaning and contact processes. The contact processes contaminate the steam with ammonia and hydrogen sulfide, which are usually treated by steam stripping.

Boiler circuit wastewaters were found to be an average of 26% of the total process wastewaters at the 12 refineries studied. Measures to reduce boiler circuit wastewaters by an average of 40% were identified at ten of the 12 plants. Steam balances for each refinery before and after boiler circuit optimization are presented in Table 1. The fates of boiler circuit feedwaters before and after optimization are given in Table 2 as average percentages for the 12 refineries.

The study found that an average of 37% of boiler feedwaters are presently lost to the sewer in various forms. These sewer losses include clean and sour condensate, boiler blowdown, and pretreatment wastes such as filter backwash, clarifier sludge, and softening regenerant. An average of 20% of the boiler feed is vented to the atmosphere in the form of flares, pressure letdowns, steam tracing losses, untrapped steam, washes, process injections, air preheating,

reboiling, and random venting to accommodate temporary needs, atomizing, and de-aeration. An average 38% of the boiler feed is recovered as clean condensate that is collected and reused as boiler feed. An average of 5% of the boiler

**Table 2. Average condition of boiler circuit feedwater.**

	Boiler Feed, %*	
	Before Optimization	After Optimization
To Sewer:**		
Pretreatment Wastes	3	3
Boiler Blowdown	8	4
Clean Condensate	20	12
Sour Condensate	6	5
To Recovery:		
Condensate	38	53
To Vent:		
Losses	20	16
To Other:***		
Clean Condensate	1	1
Sour Condensate	4	6

\*Boiler feed includes recovered condensate and pretreatment system intake of raw water.  
 \*\*Clean and sour condensate to sewer include process uses and losses.  
 \*\*\*Other uses include desalter make-up, cooling tower make-up, and spray pond make-up.

feed is recovered as sour and/or clean condensate that is collected and reused as cooling tower make-up, spray pond make-up, and de-salter make-up.

Steam condensate recovery and vent loss elimination is a wastewater reduction technique that is applicable to many refineries. For the plants visited, losses to the sewer can be reduced to an average of 24% of boiler feed by recovery of condensate for boiler feed, elimination of vent losses, and reuse of sour condensate as desalter make-up. Condensate recovery for boiler feed could be increased to 53% of boiler feed by the installation or expansion of piping systems to collect steam lost by overheating, tracing, tank heating, traps, utility, and leaks.

Vent losses can be reduced to an average of 16% of boiler feed by eliminating vents at process units, turbines and

steam traps. An average of 11% of boiler feed could end up in the form of sour condensate. This sour condensate requires stripping for ammonia and hydrogen sulfide removal. Stripped sour water can be reused as make-up for cooling towers or spray ponds that operate at low cycles of concentration and as make-up for desalters. One refinery reports that stripped sour water can be used as fluid catalytic cracker washwater if plugging problems due to calcium deposition are overcome.

Condensate recovery was the most economically attractive reduction technique studied. Hardware required for this technique normally requires piping and pumps, but can also include collection tanks, condensers, replacement or installation of steam traps, and conversion of turbines to electric motors. A permanent team of full-time refinery

**Table 3. Cost of condensate recovery and reuse and vent loss reduction.**

Refinery	Technique*	Reduction of Flow to Sewer, Mgal/d	Capital Cost, \$	Annual Operating Cost, \$	Total Annual Cost, \$	Annual Savings, \$	Base Year	Flow Reduction Unit Cost \$/yr per gal/d**
1	Condensate Recovery and Vent Loss Reduction	0.204	450,000	5,000	108,000	53,000	1978	0.64
	Reuse for Desalter Make-up and FCC Washwater	0.190	40,000	2,000	12,000	26,000		0.07
2	Condensate Recovery and Vent Loss Reduction	0.030	55,000	1,200	15,000	44,000	1978	0.55
4	Condensate Recovery and Vent Loss Reduction	0.562	644,000	76,000	238,000	502,000	1978	0.47
	Reuse for Desalter Make-up	0.11	70,000	1,500	19,000	8,000		0.19
5	Condensate Recovery and Vent Loss Reduction	2.1	2,400,000	170,000	770,000	4,210,000	1979	0.37
6	Condensate Recovery and Vent Loss Reduction	0.070	186,000	31,000	78,000	339,000	1978	1.20
	Reuse for Desalter Make-up	0.167	44,000	700	12,000	5,800		0.08
7	Condensate Recovery	0.10	1,610,000	—	403,000	205,000	1978	4.40
8	Condensate Recovery and Vent Loss Reduction	0.54	375,000	8,700	103,000	1,710,000	1979	0.19
	Reuse for Desalter Make-up	0.20	130,000	3,000	36,000	192,000		0.18
9	Condensate Recovery Reuse for Cooling Tower Make-up	0.02	5,000	—	2,000	15,000	1979	0.10
		0.42	710,000	205,000	383,000	15,000		0.91
10	Condensate Recovery and Vent Loss Reduction	0.03	125,000	—	32,000	60,000	1979	1.10
12	Condensate Recovery Reuse for Desalter Make-up	0.07	600,000	—	150,000	—	1978	2.40
		0.29	681,000	3,470,000	3,640,000	—		14.00

\*Recovered condensate is reused for boiler feedwater, desalter make-up, cooling tower make-up, and fluid catalytic cracking unit washwater. Vent loss reductions will result in less boiler blowdown and pretreatment waste streams entering the sewer.

\*\*1979 \$.

SI Conversion: L = gal × 3.79

**Table 4. Refinery cooling water systems management.**

Refinery	% Once-Thru Cooling by Btu	% Air Cooling by Btu	Number of Cooling Towers	Avg. Cycles of Concentration Before/After Reduction/Max.*	Treated Effluent as % of Make-Up Before/After Reduction	Operating Limits, Recommended Max., mg/L**
1	0	25	13	3.0/4.9/7	0/0	Hardness = 750 Cycles = 4 TDS = 2,000; SiO <sub>2</sub> = 150; Alkalinity = 220; Hardness = 700
2	5	40	1	4/4/4	0/0	
3	0	9	13	8.6/8.6/10	0/0	
4	5	6	Spray Pond	1.1/1.7/2	6/0	NA***
5	31	3	4	1.8/2/5	54/100	Mg = 50
6	1	0	5	2.2/2.8/7	0/0	Cycles = 7
7	68	10	1	2/4/5	0/0	Cycles = 5
8	60	20	1	2.5/4.5/7	0/0	Cycles = 7
9	0.1	23	12	6/8/10	0/0	Cycles = 10
10	0.1	11	9	3.9/3.9/5	0/7	Ca = 1,200
11	0.5	15	2	9.5/9.5/15	0/30	TDS = 2,000
12	0.3	8	19	3.7/3.5/4.4	0/66	TDS = 2,000

\*The maximum achievable cycles of concentration as based on water quality considerations.

\*\*Ca - Calcium hardness as CaCO<sub>3</sub>; Mg - Magnesium hardness as CaCO<sub>3</sub>; Hardness - Total hardness as Ca and Mg; TDS - Total Dissolve; SiO<sub>2</sub> - Silici; Alkalinity - Total alkalinity as CaCO<sub>3</sub>.

\*\*\*NA - Not applicable or data not available.

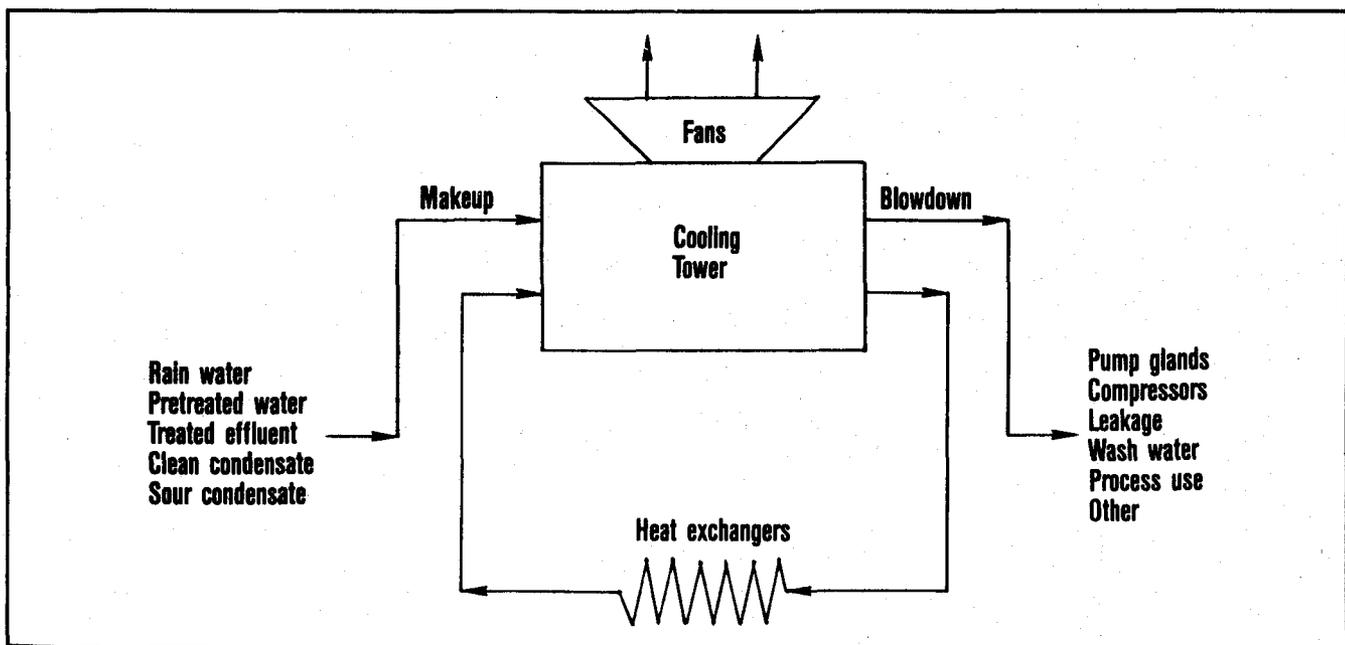
SI Conversion - kJ - Btu x 1.055

personnel would be required to maintain some recovery systems. The recovery of condensed and vented steam and their reuse as boiler feed has benefits in addition to minimizing direct losses to the sewer: boiler pretreatment wastewater volumes will be decreased since clean condensate requires no pretreatment, and energy will be conserved by

the return of high-temperature water to the boilers.

*Costs.* The refineries studied may be categorized into three types that represent the status and cost of each plant's condensate recovery and reuse systems.

The first type includes refineries that recover and reuse approximately one-half of the original boiler feed by exten-



**Figure 2. Cooling tower make-up sources and blowdown streams.**

**Table 5. Cost of cooling tower blowdown control.**

Re- fery	Technique	Number of Towers	Existing/ New Cycles of Concen- tration	Flow Reduction Mgal/d	Capital Cost, \$	Annual Operat- ing Cost, \$	Total Annual Cost, \$	Annual Savings, \$	Base Year	Flow Reduction Unit Cost \$/yr per gal/d*
1	Blowdown Collection and Pump Cooling Re- cycle	13	3/4.9	0.421	510,000	8,500	136,000	93,000	1978	0.36
4	Blowdown Collection	Spray Pond	1.1/1.7	1.73	239,000	5,000	65,000	120,000	1978	0.04
6	Pump Cool- ing Service Reduction Blowdown Collection and Wash- water Ser- vice Elim- ination	5	2.2/2.8	0.280	69,000	2,000	19,000	16,000	1978	0.07
7	Valve Re- placement and Blow- down Con- trol	1	2/4	0.10	100,000	0	25,000	4,000	1978	0.28
8	Blowdown Collection and Pump Cooling Re- cycle	1	2.5/4.5	0.16	60,000	0	15,000	30,000	1979	0.09
9	Operation Control and Tur- bine Jacket Cooling Service Elimina- tion	12	6/8	0.10**	10,000	0	2,500	8,700	1979	0.03

\*1979 \$.

\*\*Cooling tower operation controls at Lion will reduce blowdown by 0.10 Mg/d. However, required use of municipal sewage treatment plant effluent as make-up, in the future, could force overall increase in blowdown by 0.28 million gal (10,610 m<sup>3</sup>/d).

SI Conversion: L - gal × 3.79; m<sup>3</sup> - gal × 0.00379

sive collection systems. The unit costs of recovering more condensate are high, since the existing collection networks are reducing their capacities and processes would require major modification.

The second type includes plants that have existing collection networks that may be tapped for additional condensate recovery. The unit costs of additional recovery are lower than those for the first type of plant. As this type attempts to increase its recovery and reuse of condensate, the cost per gallon will rise as the refinery resorts to recovery techniques that are less economically attractive than those already committed.

The third type includes refineries which recover less than one-fourth of their boiler feedwaters. Existing recovery is limited to internal systems at boilers and turbines, and no piping network is available for recovering condensate at other locations. The cost of additional recovery includes the installation of extensive piping networks.

Table 3 presents a cost summary of the additional con-

densate recovery and vent loss reduction techniques identified at ten refineries. These methods reduce flow to sewers by recovering and reusing condensate losses for boiler feedwater, desalter make-up, and cooling tower make-up, and by reducing boiler blowdown and pretreatment waste streams.

Savings realized by recovered high-temperature condensate and reduced pretreatment requirements were identified at nine of the ten plants listed and, in some cases, are substantial. However, these cost savings are difficult to assess among the refineries since the value placed on heat is not consistent.

### Cooling tower blowdown control

At refineries that used cooling towers, the cooling tower blowdown streams amounted to one-third of the total refinery process wastewaters. Some refineries rely on air cooling to supply 20 to 40% of their cooling needs by Btu. Use of

**Table 6. Cost of general process wastewater reduction.**

Refinery	Technique	Reduction of Flow to Sewer, Mgal/d	Capital Cost, \$	Annual Operating Cost, \$	Total Annual Cost, \$	Annual Savings, \$	Base Year	Flow Reduction Unit Cost \$/yr per gal/d*
2	Reuse of once-thru pump and compressor cooling water for desalter make-up	0.036	12,000	500	3,500	3,100	1978	0.11
4	Elimination of water cooled air-conditioning systems	0.22	100,000	1,000	26,000	15,000	1978	0.13
5	Recycle system at pipe still	1.0	290,000	0	73,000	0	1979	0.07
6	Replacement of barometric condensers with heat exchangers tied to cooling tower system	0.216	250,000	3,800	66,000	7,500	1978	0.34
7	Reduction of once-thru pump gland cooling water by use of mechanical seals	0.12	108,000	0	27,000	0	1978	0.25
8	Reduction of once-thru pump gland cooling water by use of mechanical seals	0.48	150,000	0	38,000	14,000	1979	0.08
9	Installation of fixed skimmers in guard basins to reduce skimming rate	0.41	500,000	5,300	130,000	12,000		0.35
10	Reuse of isocracket cooling and scrubber water for cooling tower make-up	0.06	30,000	0	7,500	2,100	1979	0.13
	Reuse of once-thru propane condenser cooling water for cooling tower make-up	0.39	108,000	2,000	29,000	9,000	1979	0.07

\*1979 \$.

SI Conversion: L - gal x 3.79; m<sup>3</sup> - gal x 0.00379

cooling towers is less prevalent at refineries that have access to large water supplies that can be used for once-through cooling systems. Table 4 presents a summary of the cooling water systems at the 12 refineries visited. Figure 2 represents possible cooling tower configurations.

Some refineries tightly manage their cooling tower systems by monitoring water quality and by controlling blowdown volumes. As evaporation takes place within a tower, nonvolatile impurities in the make-up water are concentrated and must be deliberately removed or blown down from the system. The major dissolved impurities in cooling tower make-up water are silica, sodium, calcium, magne-

sium, iron, bicarbonates, chlorides and sulfates. Concentrations of these parameters are controlled by cooling tower blowdown to prevent corrosion, scaling or fouling. The maximum operating cycles of concentration usually depend on only one or two parameters whose concentration in the make-up water is comparatively higher than other parameters.

Most refineries use total hardness, total dissolved solids, or conductivity as limiting parameters for operation. Cooling tower make-up is sometimes pretreated for removal of calcium, magnesium, silica or total suspended solids by cold lime or sodium zeolite softening, clarification or filtration.

**Table 7. Cost of treated effluent reuse.**

Refinery	Reuse Flow, Mgal/d	Capital Cost, \$	Annual Operating Cost, \$	Total Annual Cost, \$	Annual Savings, \$	Base Year	Flow Reduction Unit Cost \$/yr per gal/d*	Remarks
3	0.31	510,000	28,000	156,000	0	1978	0.55	Reused in firewater system. Cost includes dual media filtration and piping system.
5	2.7	150,000	0	38,000	0	1979	0.01	Reused for cooling tower make-up. Utilizes existing piping and connections. Cost includes additional piping. No additional operating costs anticipated.
6	0.17	287,000	4,500	76,000	2,800	1978	0.49	Reused in firewater system. Cost includes aeration basin modification to provide storage.
7	0.44	315,000	10,000	89,000	0	1978	0.22	Reused for cooling in boiler house and catalytic cracking unit, utility purposes, pump gland cooling, and exchanger boxes. Cost includes piping network for distribution.
	0.55	10,000	1,000	3,500	0		0.01	Reused for heat exchanger cooling during 85% of the year. Cost includes lined pond and piping.
	1.73	1,000,000	0	250,000	0		0.16	Replacement of barometric condensers with surface condensers that can use treated effluent for cooling during the entire year.

*Continued on next page*

Chemicals are usually added to recirculating water to adjust pH for the prevention of dissolved solid precipitation, to control biological growth, and to inhibit corrosion or scaling at heat exchangers.

Refinery 3 exemplifies optimal cooling tower operations. The plant's 13 towers operate between seven and ten cycles of concentration with cold lime softening and recarbonation of make-up water and acid addition. Blowdown is operator-controlled, and some portion of the blowdown is used for pump gland cooling. Manpower requirements include 78 hours per week supervisory time and 52 hours per week technical time in the laboratory, in process areas, and at cooling towers.

Two refineries studied presently use treated wastewater effluent as make-up to their cooling towers. Treated effluent TDS concentrations are considerably higher than raw intake water. Refinery 5 operates its cooling towers at about

2.2 cycles; hence, the recirculating water dissolved solids concentration tends to remain below operating limits. Blowdown is uncontrolled. Hardness in the reuse water is not a problem since the pretreatment softening sludge, which is very high in hardness, does not enter the treatment system.

Most refineries tend to pay insufficient attention to cooling water systems management. Cooling tower cycles of concentration tend to be very low during the summer as evaporation increases or if make-up water is very hard or, in the more likely case, if blowdown is uncontrolled. Uncontrolled blowdown is not operator-controlled, is erratically drawn to serve other uses such as pump gland cooling, compressor cooling, and washwater, and can also take the form of leakage. Refinery personnel were able to identify 25 to 75% of the blowdown at the plants studied as potentially controllable, with the remaining percentage requiring a more intensive survey.

**Table 7. Cost of treated effluent reuse (Continued).**

Refinery	Reuse Flow, Mgal/d	Capital Cost, \$	Annual Operating Cost, \$	Total Annual Cost, \$	Annual Savings, \$	Base Year	Flow Reduction Unit Cost \$/yr per gal/d*	Remarks
9	0.11	15,000	0	3,800	3,900	1979	0.03	Reused for cooling service. Cost includes piping system.
	0.54	400,000	10,000	110,000	0		0.20	Reused for cooling service in crude unit and for coke sluicing operation. Cost includes heat exchanger and piping systems.
10	0.31	610,000	102,000	255,000	7,000	1979	0.82	Reused for cooling tower make-up. Cost includes dual media filtration, chlorination, storage tank, and piping system.
11	1.1	1,600,000	340,000	740,000	0	1979	0.67	Reused for cooling tower make-up and wash water. Cost includes dissolved air flotation, dual media filtration, piping system, and separate discharge of ballast and softener regenerant streams.
12	21.	15,400,000	5,340,000	9,190,000	235,000	1978	0.48	Reused for firewater, process hose water, and cooling tower make-up. Cost includes dissolved air flotation, chemical addition, dual media filtration, piping system, and separate discharge of ballast and softener regenerant streams.

\*1979 \$.

SI Conversion: L - gal × 3.79; m<sup>3</sup> - gal × 0.00379

The fate of uncontrolled blowdown, the quality of make-up water, and the limiting parameters vary among the refineries studied. Methods for reducing blowdown also depend on each refinery's cooling water system alignment. Some modifications, which may be commonly applied, include:

1. Recycle cooling water from pumps, compressors, and sample boxes that use blowdown.
2. Replace existing oil-leaking pump gland packing with mechanical seals to permit collection and recycle of blowdown to cooling tower.
3. Reduce use of pump gland cooling water where presently overused or eliminate service completely.
4. Upgrade maintenance of existing systems to reduce leakage and sump overflow.

The cooling tower cycles of concentration for the refineries visited averaged 4. At six of the plants, blowdown can be reduced by an average of more than one-half and cycles of concentration increased by the elimination of uncontrolled blowdown. Even higher cycles of concentration could be achieved, based on water quality considerations, if a more

intensive survey of uncontrolled blowdown sources were conducted.

Costs for reducing blowdown are not easily determined, even though some techniques can be commonly applied. Increasing the cycles of concentration at cooling towers may require a greater expenditure for chemicals to control operating parameters. But, reducing volumes could actually reduce chemical addition if no problems develop. Manpower for laboratory services and cooling systems management may also require greater expenditures. However, increases in chemical and labor costs cannot be accurately predicted by refinery personnel. A savings could be realized by a decrease in treatment requirements and a possible decrease in chemical costs.

Table 5 presents cost data for the six refineries where potential cooling tower blowdown control measures were identified. The total cost of controlling blowdown is generally greater at plants that depend heavily on cooling towers and whose blowdowns are not collectible at one point. Refineries 1 and 6 are of this type. Blowdown control at No. 1 requires replacement of existing oil leaking pump seals

**Table 8. Refinery wastewater sources before flow reductions.\*\***

Refinery	Cooling Tower Blowdown	Boiler Circuit	Desalter	General Process Uses*	Treated Effluent Reuse
1	36%	39%	11%	14%	13%
2	8	25	33	34	0
3	30	26	8	36	0
4	65	25	4	6	13
5	13	25	4	58	42
6	32	18	12	38	0
7	2	6	0	92	60
8	6	35	8	51	0
9	9	25	3	63	48
10	33	27	15	25	3
11	9	40	6	45	0
12	12	16	3	69	0

\*General process uses vary from plant to plant and include firewater, wash water, barometric condensers, pump cooling, exchanger cooling, and miscellaneous uses.

\*\*As a percentage of total refinery process generated wastewater.

that use blowdown, and the installation of a collection network. Replacement of the gland seals with mechanical seals accounts for one-fourth of the capital cost of blowdown control at No. 1. At Refinery 6, some 75% of the identified blowdown losses can be controlled by an ongoing pump elimination program and the installation of a collection system to recover the remaining blowdown.

Those refineries that have relied heavily on once-through cooling water to supply a plant's needs tend to have evaporative cooling systems that are not tightly managed. Refinery 4 with its spray pond and Refinery 7 are of this type. No. 4 can reduce the flow from its spray pond to the sewer by a total of 70%. The recycle of blowdown that is used by the refinery's detergent additive plant and the dismantling of cooling fixtures from 248 pumps that use blowdown will reduce blowdown a total of 2.16 million gal (8,190 m<sup>3</sup>)/d. Refinery 7 must repair a series of faulty valves to control blowdown from their only cooling tower. The blowdown stream can then be controlled at one point and discharged to the end-of-pipe treatment system.

Refineries 8 and 9 have newer systems that were designed to manage cooling tower blowdown. No. 8 has only one cooling tower that was constructed as part of a plant expansion in 1975. The system was designed to minimize the loss of pump gland cooling water. However, since installation, the operator-controlled blowdown valve has been closed and return lines disconnected. Uncontrolled blowdown can be eliminated by placing mechanical seals in a total of 20 pumps. Automatic controls have recently been installed on each of Refinery 9's cooling towers. When these controls have been tested and are operating properly, blowdown can then be managed more closely. Also, a turbine jacket cooling stream can be eliminated by switching this cooling service to treated effluent.

### General process uses

General process uses contribute an average 44% of the wastewater volume at the refineries studied. General process uses vary but can include barometric condenser cooling water, firewater, washwater, machine cooling, and exchanger cooling. In some processes, use of treated water is acceptable.

The conversion from barometric condensers to surface condensers is a recognized technology. Barometric condens-

ing is a contact cooling process that sometimes requires large volumes of water. However, elimination of the barometric condenser wastewater stream may drastically impact biological wastewater treatment operations, since barometric condensers provide a substantial supply of organics and heat to the biological system.

Firewater and washwater are generally drawn off the same system, since actual firewater uses are erratic. Sources of loss to the sewer from poorly managed washwater systems include overflowing sumps, freely running hoses, temporary exchange coolers, and underground leakage. Underground leaks are not easily corrected, but problems of poor management may be overcome by an effective water conservation program, since these losses are operator-controlled. Exchangers and machines such as pumps and compressors that are not part of a recirculating cooling system are integrated with firewater or once-through systems. Due to their alignment with existing systems, these sources are difficult and expensive to eliminate or to tie into a recirculating system.

Costs. General process uses vary from plant to plant with no common technique found applicable to any group or type of refinery for which costs may be estimated. Table 6 presents a cost summary of general process wastewater reduction measures identified at eight of the 12 refineries studied. Reusing once-through cooling waters for desalter make-up, cooling tower make-up, or process water was found to be more cost-effective in reducing wastewater discharge to the sewer than other alternatives, such as the replacement of barometric condensers.

### Reuse of treated effluent

Treated effluent is currently being reused at 8 of the 15 refineries visited for this study. Refineries have sought to reuse treated wastewater to replace costly raw water or to meet effluent guidelines. The total dissolved solids (TDS) concentration of the treated effluent is of primary concern to plants that presently reuse it. A TDS concentration of 1,000 mg/L or less is generally considered acceptable for the reuse of effluent as pump and compressor cooling water, firewater, and washwater. Refinery 7 has had success reusing effluent with 500 mg/L of TDS as exchanger and barometric condenser cooling water. Exchangers and condensers are more sensitive to TDS than pumps or compres-

scars because of a higher thermal gradient across the exchanger's cooling surface. Refinery 1 has had success using effluent with 1,500 mg/L of TDS for the liquefaction of coke fines to limit dust and enable the transport of the solids.

The reuse of effluent as cooling tower or spray pond make-up depends on the cycles of concentration of that cooling unit. The maximum allowable limits for recirculating water quality cannot be exceeded, as explained earlier. Refinery 4 reuses effluent in its firewater system which supplies a portion of the make-up to a spray pond. The spray pond is the only evaporative cooling system at the plant and operates at very low cycles of concentration. The TDS of treated effluent at both plants is less than 1,000 mg/L and cycles are less than 2.

Refinery 9 uses an average of 48% of its treated process wastewater for pump gland cooling, service water, and for dust control at its coke pile. Refinery 10 is successfully reusing a portion of its treated wastewater as make-up to its desalting units.

Potential areas for additional reuse of treated effluent were found at eight of the 12 refineries for which possible flow reduction alternatives were identified. An average of 45% of the total process generated wastewaters could be reused for various purposes after end-of-pipe treatment at ten of the 12 refineries that would then be using treated effluent.

Refinery 3 considers the quality of its effluent, after filtration, to be acceptable for firewater and is currently modifying the plant's wastewater flow scheme to accommodate reuse. Refinery 5 is already using 2.7 million gal (10,230 m<sup>3</sup>)/d of treated effluent for cooling tower make-up and firewater, and has an ongoing project to reuse an additional 2.7 million gal (10,230 m<sup>3</sup>)/d. Effluent can be reused at Refinery 6 to supply the firewater system since its water quality requirements are not as sensitive as other plant uses.

In addition to its present reuse practices, Refinery 7 can use effluent for utility purposes, pump gland cooling, and exchanger boxes. Replacing barometric condensers with surface condensers will allow the use of treated effluent for cooling during the entire year. Refinery 9 can increase its reuse of treated process wastewater to 60% by supplying effluent for cooling and coke-slucing operations.

Refinery 10 can supply effluent for cooling tower make-up, but must first treat it for suspended solids and ammonia removal. Both Refineries 11 and 12 were found to have high TDS waste streams contributing to their end-of-pipe treatment systems. Segregation and separate handling of these streams are necessary before final effluent can be reused. Additional treatment for suspended solids removal must also be provided before the resulting effluent can be used for cooling tower make-up, firewater or washwater.

The amount of treated effluent that can be reused depends on the degree to which the effluent is contaminated with dissolved solids. Although effluent TDS concentrations varied among the plants, none of the proposed flow reduction schemes required treatment systems for TDS removal. However, reverse osmosis is an available technology that can remove 90% of dissolved solids and 100% of suspended solids. A brine concentrator and spray evaporator system could be used to treat the reverse osmosis reject stream to boiler feed quality and produce a dry solids waste.

Costs. Table 7 presents cost data for the eight refineries where potential areas for additional reuse of treated effluent were identified. Costs per gallon reduction among the plants varied substantially, depending on the accessibility of existing treated effluent piping, the availability of existing storage capacity, and the adaptability of existing process equipment to using effluent. Little, if any, cost savings are associated with effluent reuse.

However, these plants can be grouped into two general

**Table 9. Possible reduction and reuse of wastewater sources.\*\***

Refinery	Cooling Tower Blowdown	Boiler Circuit	General Process* Uses	Reuse of Treated Effluent
1	79%	66%	0%	28%
2	0	56	31	0
3	0	0	0	19
4	70	58	-25	31
5	0	47	10	70
6	49	66	33	16
7	75	28	2	90
8	75	48	65	0
9	17	26	2	60
10	0	5	71	21
11	0	0	0	50
12	-4	8	0	67

\*Does not include effluent reuse. Only reductions resulting from process or wastewater discharge modifications are presented here.

\*\*Possible flow reduction as a percentage of source flow rate.

types. One group includes those refineries whose effluent can be reused directly without additional treatment. Refineries 5, 6, 7 and 9 are of this type. Costs for reuse at these refineries include piping, pumping and connection costs, and are based on new underground construction. Piping costs for No. 7 are high due to the difficulty of integrating new piping with old. Some refineries will not experience these difficulties due to plant layout or the ability to utilize overhead piping; hence, the estimates developed are conservative. The other group includes those refineries whose effluent requires additional treatment before reuse (Nos. 3, 10, 11 and 12). In addition to piping and pumping costs, estimates for these plants include dissolved air flotation, filtration and storage costs.

### In summary

Reuse and recycle techniques in the petroleum refining industry were found to be effective in reducing wastewater discharges. Significant wastewater reductions were found possible at 12 refineries studied. Table 8 shows the sources of wastewater at the 12 refineries studied; Table 9, the flow reductions that can be realized at each refinery by the techniques identified in the study.

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