PN-ACC-360
97368

Environmental Policy and Technology Project

Contract No. CCN-0003-Q-O9-3165-00

UKRAINE
Round 1 Environmental Audit:
Water and Wastewater Operations of
Enakievo Metallurgical Plant

Delivery Order #9, Task U-1, Subtask 1.2
September 1997

Prepared for:
U.S. Agency for International Development
Regional USAID Mission to Ukraine, Belarus & Moldova

Bureau for Europe & the New Independent States
Office of Environment, Energy & Urban Development
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INTRODUCTION.

This report constitutes an environmental site assessment conducted as part of Round I auditing activities under delivery order 9 The audit, or more accurately described as a pollution prevention assessment, was conducted at the Enakievo Metallurgical Plant. Since it was one of the first audits and designed in part to be instructive to local Ukrainians, only the water recycling and solid waste issues associated with the operation were examined

The facility is a steel mill that is typical in design and operation for the region. A process flow sheet for the plant is given in Figure 1. The plant is approximately 100 years old and it may be noted that the current thinking among upper management is older. The upper management of this operation was uncooperative during this assessment, but operating plant personnel were helpful and quite interested in identifying ways to improve the efficiency of their operations. There is however a hierarchal structure of command, whereby individual departments simply will not act on their own initiative to correct problems. A very simple example is significant water losses that were identified by drainage from waste piles. When the audit team suggested diking these discharges so that they could be collected and recycled, plant personnel commented that this would require approval from their technical director In addition, no photographs were allowed to be taken during the site study.

The study identified over 40 million U.S. dollars in recycling opportunities, and recommendations that the facility begin some feasibility studies to address the economics of engineering projects are made in this report The author does doubt, based on management attitude, that any of these recommendation will be implemented or even assessed. Despite this, the exercise was useful from several standpoints First, the concept and value of conducting detailed material balances to quantify recycling opportunities was demonstrated to Ukrainians that took part in this audit Second and perhaps most important, because the facility is similar to other steel mill operations in the region, the opportunities identified are equally applicable The general approach to the study and analysis are now being applied with greater success at the Azovstal Metallurgical Plant and the Illich Steel Plant in Mariupol.

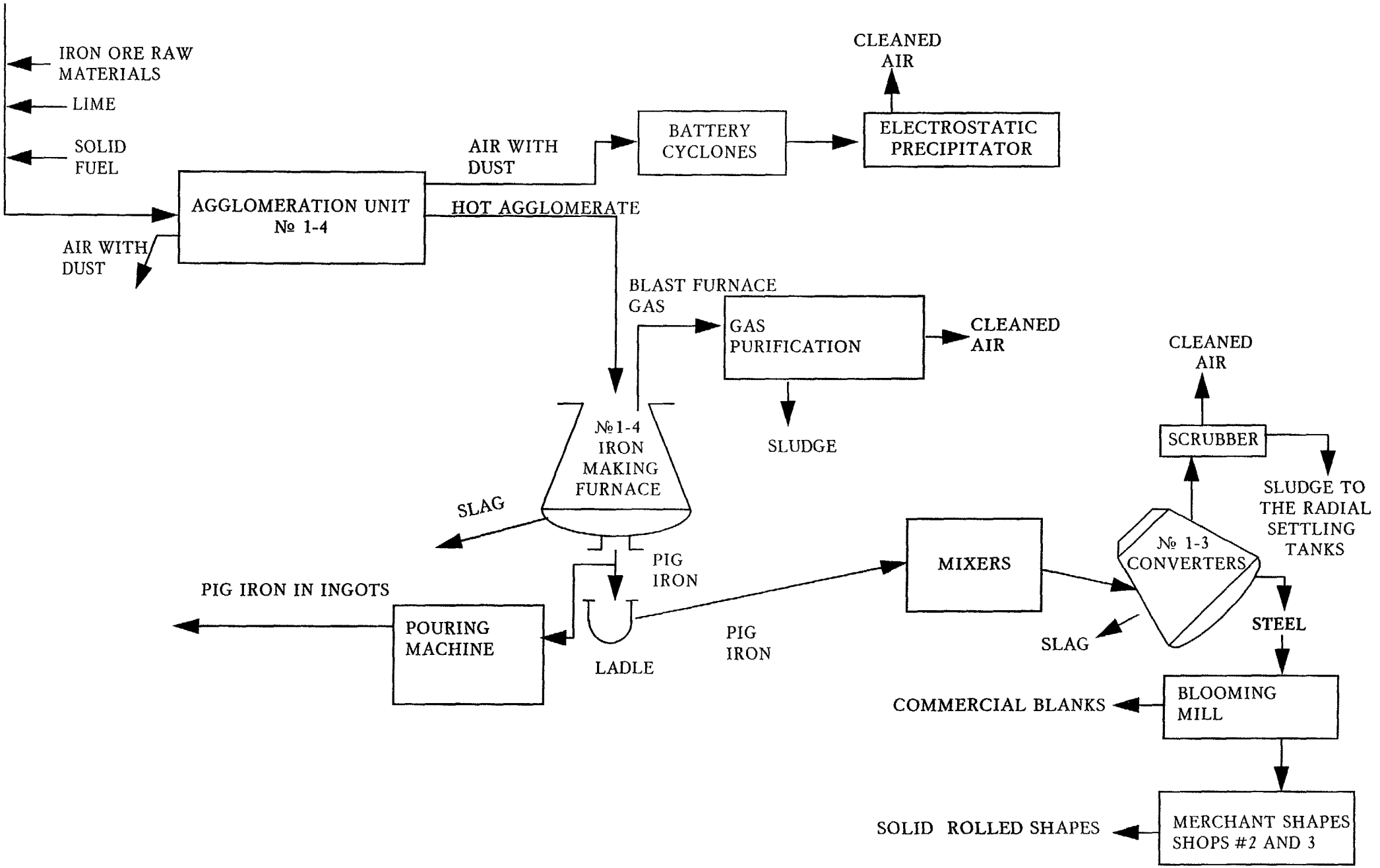


Figure 1. Enakievo Plant Flowsheet.

OVERVIEW OF ENAKIEVO METALLURGICAL PLANT.

The Enakievo Metallurgical Plant is located in the city of Enakievo in the Donetsk Oblast. It is operated and owned by Gorlovka - Enakievo industrial agglomerate. Enakievo is a very old city located near the Bulavin River, 60 km north of Donetsk The plant covers the area of 285 4 hectares The number of employees is reportedly 11,700 people, however the management of the facility would not provide accurate information on current productivity levels It is believed that the facility is actually operating below 40% capacity and more than 50% of the employees have not shown up to work in the last 3 months because salaries have not been paid

The nameplate capacity for this iron mill is ·

- agglomerate - 3.5 million tons per year;
- pig iron - 3.0 million tons per year;
- steel - 3.2 million tons per year;
- rolled products - 3.0 million tons per year.

Annual productions for the last 2 years amounted to (in million tons per year).

Product	**1995**	**1996**
Agglomerate	1,147	1,248
Pig iron	1,006	1,137
Steel	1,001	1,332
Rolled products	0,847	1,077

In 1996 the production of the agglomerate amounted to 35 7% of nameplate capacity, pig iron - 37.9%, steel - 41.63%, rolled products - 35 9% These are unofficial estimates, provided by a technical department manager who does not want to be identified in the report.

Water Supply and Consumption Characteristics.

The water supply to the subject facility relies heavily on a highly inefficient recycling scheme A number of the plant's process operations, including their Central Heating and Power Plant - Gas Vapor System, Oxygen and Blast Furnace and Oxygen Converter Shops, and operations involving granulations of slags, have their own local water supply sources. The remainder of the plant's operating departments rely on a general recycling scheme that is supplied by a massive cooling pond for its process water.

The characteristic of the local water supply systems for the different production departments are described below.

Central Heating and Power Plant - Gas Vapor System.

The water supply to this operation is based on a combination of both fresh water makeup and recycled water. Water is primarily used for heat exchanger applications, including air stream and oil cooling applications One of the principle applications is in heat exchanger applications for

turbines, as well as for cooling large feed and condensate pumps. Cooling water is discharged from the operation directly to the facility's cooling pond, which is part of the focus of this pollution prevention assessment

The water recycling operation for the turbine condensers is primarily comprised of the following pieces of equipment· three (3) massive cooling towers, each having an irrigation area of approximately 1600 m^2, and a gravity feed pipeline that is roughly 1400 mm in diameter

The recycled water circulation rate varies according to the number of working turbo blowers and turbo generators For five operating units, the circulating consumption amounts to approximetely 14 000 cm per hour. The ratio of fresh water to recycled in the system typically varies between 0.14 and 0 26 throughout the year.

The fresh water supply can be described as brackish and there are considerable equipment fouling problems. The fouling is a result of calcium carbonate and river sediment deposits.The preparation of make up water for steam generators is based on a water treatment facility that uses the following process steps: pretreatment with lime addition, clarification, filtration, two-stage sodium (Na) cationization. The main equipment in the water treatment plant are:

-3 clarifiers d=9m.
- equipment for preparation and dosing of lime solution.
- 8 mechanical filters d=3m
-9 Na-cationizing filters for a 1st stage operation d=3m
- 5 Na - cationizing filters for a 2nd stage operation d=3m

The capacity of the water treatment operation is on the average 352 cm per hour, but the efficiency is low.

Oxygen Shop.

Water in the shop is again used for heat exchanger purposes Water cooled units are mostly end-pipe gas coolers and oil coolers for compressors, air coolers for electric motors and oil coolers for turbine expansion engines The water supply used for cooling these units is also based on a recycling system.The recycling system is comprised of a large centrifugal pump that is quite old and cooling towers designed with a film irrigator area of 1600m^2. Gravity feed and pressure pipe lines are the basic facilities of the recycle system. The water recirculation rate is typically 13,300 cm per hour. The average annual ratio of fresh water feed to recycled is 0.28.

Part of the water from recycling system (122 cm per hour) goes to the agglomeration shop. Fresh feed water is used to compensate for losses from the recycle system. The local recycle system has serious equipment scaling problems due to calcium carbonate derived from the river water

The equipment fouling problem is noteworthy in this operation as well as most of the heat exchange applications throughout the plant because of its implication to energy conservation issues Although the plant would not permit any direct thermal measurements during the site investigation, some internal surfaces for heat exchange equipment were examined These surfaces showed up to several mm to perhaps cm buildup of calcium deposits. Under such conditions, the efficiency of thermal heat exchanger operations is likely only operating at perhaps 15% or less than the thermal efficiency of bare metal. We attempted to make this point with plant operating personnel and recommended they consider simple techniques like installing more efficient settlers or knock out drums in the water softening stages, as well as longer settling times and the use of polymeric coagulation agents during pretreatment. Unfortunately, plant operators

and management did not take these comments seriously and indicated that there are no funds available for any improvements to their operation.

Agglomeration Shop.

Water supply is used for cooling pipes on agglomeration units, for valves and for cutters for lime burning furnaces, oil systems for bag houses and exhaust fans, and for dust washing from scrubbers, wetting of charge and cooling of returns of agglomerate streams

The water supply to the agglomerating units is part of the recycled water supply system for the oxygen shop The discharge is about 96 0 cm per hour Other consumers in this department use recycled water at a rate of about 26 cm per hour. All direct consumers except for operations involving the wetting of charge and cooling of return water, discharge their waste water directly to a sewer system. The plant personnel would not disclose where the sewer ultimately deposits but we believe it is to the local river.

Blast Furnace Shop.

This operation relies on two recycling systems for its water supply

Cooling Pond Recycling

This system provides cooling for various blast furnace elements, and also for cooling of pig iron on the pouring units and in the cars In addition, small amounts of water are used for the preparation of fireproof solutions and lime mixtures, and also for watering of the working lots for dust suppression purposes Water that is supplied to the blast furnace from the cooling pond is returned to the cooling pond

Gas Cleaning Operation Recycling

Each blast furnace is equipped with dry dust catchers and wet scrubbers (both conventional and Venturi-type). Recirculated water is fed to the scrubbers to remove particulates from process air streams Water from the plant cooling pond along with various sources of waste water supply this operation.

The primary components of the recycle system are:

- circulating pumping station;
- transferring pumping stations ;
- radial settlers (d=36m - 2, d=30m - 2);
- sludge pumping stations;
- gravity and sludge pipe lines, gravity settling basins;
- forced draft cooling tower.

Waste waters derived from gas cleaning operations are sent to radial settlers through gravity settlers or pans. Clarified water is supplied to the circulating pumping station and then, without cooling, to the gas cleaning facilities by means of pumps Sediment from radial settlers is pumped into the sludge pond in the form of a viscous sludge that is about 20 to 50% solids on a weight basis

The water recycling rate is about 3100 cm per hour, and the ratio of fresh to recycled water is

typically 0 16 There appears to be a significant blowdown practice which thus requires a large amount of makeup water from the pond and we suspect higher fresh water feed than was estimated from flowmeter measurements observed during the audit

Although there is a low value for the ratio of water recycling, the generation of sediments of calcium carbonate is a major problem in the recycling system It is caused by the peculiarities of the technological process (high concentration of carbon dioxide in the blast furnace gas, presence of calcium compounds in the dust, conducting of the process under pressure) The total salt content of the water in the recycle stream is about 30% Recycled water is additionally polluted by cyanides (up to 0 5 g/cm), thiocyanate (up to 8 8 g/cm) and phenols (0 1 g/cm). The phenols likely come from the neighbouring merchant Coke -Chemical Plant who deposits some of their waste process waters in the steel mill sludge and cooling ponds. The concentration of ammonium ions was measured to be 88 g/cm.

Oxygen-converter shop.

Water for the oxygen-converter and blast furnace shops is supplied by two sources.

Clean Water Recycling.

This system provides cooling water for the tuyeres of the converters, bag houses, wet scrubbers, and covers of the repairing aperture on the boilers Spent heated water is fed to the graduators for cooling and is recycled The average consumption of recycled water is 1885 cm per hour The system's blowdown is used for lime -burning and tar-bonded dolomite departments, and also for the make up of the recycling water supply system for gas cleaning operations in the oxygen converter shop The make up of the recycling system is derived from the cooling pond and fresh water supplies.

Recycling System for Gas Cleaning

The gas outlet channel of each converter is equipped with one primary scrubber, several Venturi scrubbers and a safety trap. The main facilities of the recycling system are: a circulating pumping station, a radial sludge pond, a sludge pump station, a cooling tower, and also a gravity settling basin and connecting pipelines.

Dust containing waste waters from gas cleaning operations go to a radial sludge pond from whence clarified water goes to the circulating pumping station and is sent through the recycling loop. Captured dust is delivered by pumps to the sludge pond where it is accumulated along with dust from the blast furnace gas cleaning stage. The circulating rate for water is 620 cm per hour. The water losses are compensated by blow down of fresh water supplied from the clean water recycle loop The ratio of fresh to recycle water is 0.29.

Particulates from gas cleaning operations as well as sludges from the blast furnace have the largest impact on water quality. There is a large percent of lime in the dust (up to 10%) which has led to the build up of calcium carbonate and magnesium hydroxides in the system, which have contributed to equipment scaling problems.

Rolling Mill Operations.

There are three rolling mill shops Cooling water to this operation is derived largely from the

cooling pond Recycled water in the shops is used for the cooling of different equipment components There are two types of consumers The first category includes various equipment that is supplied non-polluted water. These include: soaking pits (for cooling pipes, pounders, slide valves), oil coolers and air coolers

The second type of consumer uses unheated water that is highly contaminated with oil and scale deposits These include. bearings, rollers of working stands,roller conveyers for rolling mills, cutters of hot and cold cutting of blanks, hydroscaling operations, bearings and hydro - compressions of the gaskets of the pumping units and other equipment.

Polluted waste waters from the water cooled units on the mills are sent to gravity settlers and scaling pits, and then pumped to secondary horizontal settlers for final purification. After purification they go to the cooling pond. Mills "360" and "280" of shop #2 are exceptions. In these mills polluted wastes with the clean waters are discharged into the secondary settler without going to the scaling pit. In rolling mill #3 polluted water is discharged into the scaling pit with the clean water of the machinery hall.

Recycled water in the rolling mill production is contaminated with scale and oils.The average concentration of the suspended matter in the clarified water after the settlers is approximately 160 g/cm, and the average concentration of oils is 13 g/cm.

Processing of Metallurgical Slags.

Both blast furnace and converter slags are processed in the plant Converter slag is slaked and foamed by water in the "converter dump" with the subsequent utilization in the blast furnace production and as road construction material Blast furnace slag is processed and utilized completely About 50-65% of the slag is granulated The rest of the slag is slaked and foamed by water, then it is dried and sold

In this facility granulated slag is produced by a semi-dry method. Water supply to the granulating unit is largely recycled Two- sectional horizontal settlers, two- sectional reservoirs of clarified water, and a circulating pumping station are included in the design. The recycle system is supplemented by water from the cooling pond.

A significant amount of water drainage occurs from sludge piles. This drainage overflows to a nearby pond From this pond the discharge of the pumping station goes to an aeration pond where a portion of hydrogen sulfide is removed. The water is then sent to the cooling pond. The discharge from the sludge piles is highly alkaline (pH=11.6-12.1) and is polluted by sulfur compounds (largely mercaptans like hydrogen sulfide which are highly toxic).

Additional Productions.

These consumers are railway, mechanical, shaped casting and other shops.The consumers of the railway shop (the rolling stock, a locomotive depot, garages) use fresh industrial water. The spent water is discharged to the cooling pond.Fresh feed water is also used in the mechanical shop with discharges sent to the cooling pond. Consumers in the shaped casting shop are heat exchangers for the open hearth furnace and electric furnaces Their source of water supply is the cooling pond

The other shops are the pile driving shop, metal construction shop and others Only small amounts of industrial water are used by these consumers.

BALANCE OF WATER CONSUMPTION AND DISCHARGES AND CHRACTERISTIC OF PRODUCTION WASTES.

Central Heating and Power Plant - Gas Vapor System.

A material balance of the water consumption and discharge for the Central Heating Power Plant-Gas vapor system is shown in Figure 2. Losses amount to about 454 c.m. per hour due to evaporative losses , and condensation losses in cooling towers (222.5 c.m.per hour), losses of condensate by steam consumers (211 c.m. per hour) and losses from feed water supplied for evaporative cooling of furnaces (20.5 c.m.per hour).

About 527.5c.m.per hour of waste waters goes to the plant cooling pond from the water supply system. This amount can be broken down to:

- 365.5 c m.per hour - water for the blowing of the recycle system of the cooling of turbine condensers, and also waste waters of the consumers that work on the direct-flow basis,
- 41 5 c m per hour - waste waters of the chemical water pollution control facilities,
- 95 5 c m per hour - water for the blowing of the steam generators,
- 25 0 c m per hour - steam condensate of the plant consumers

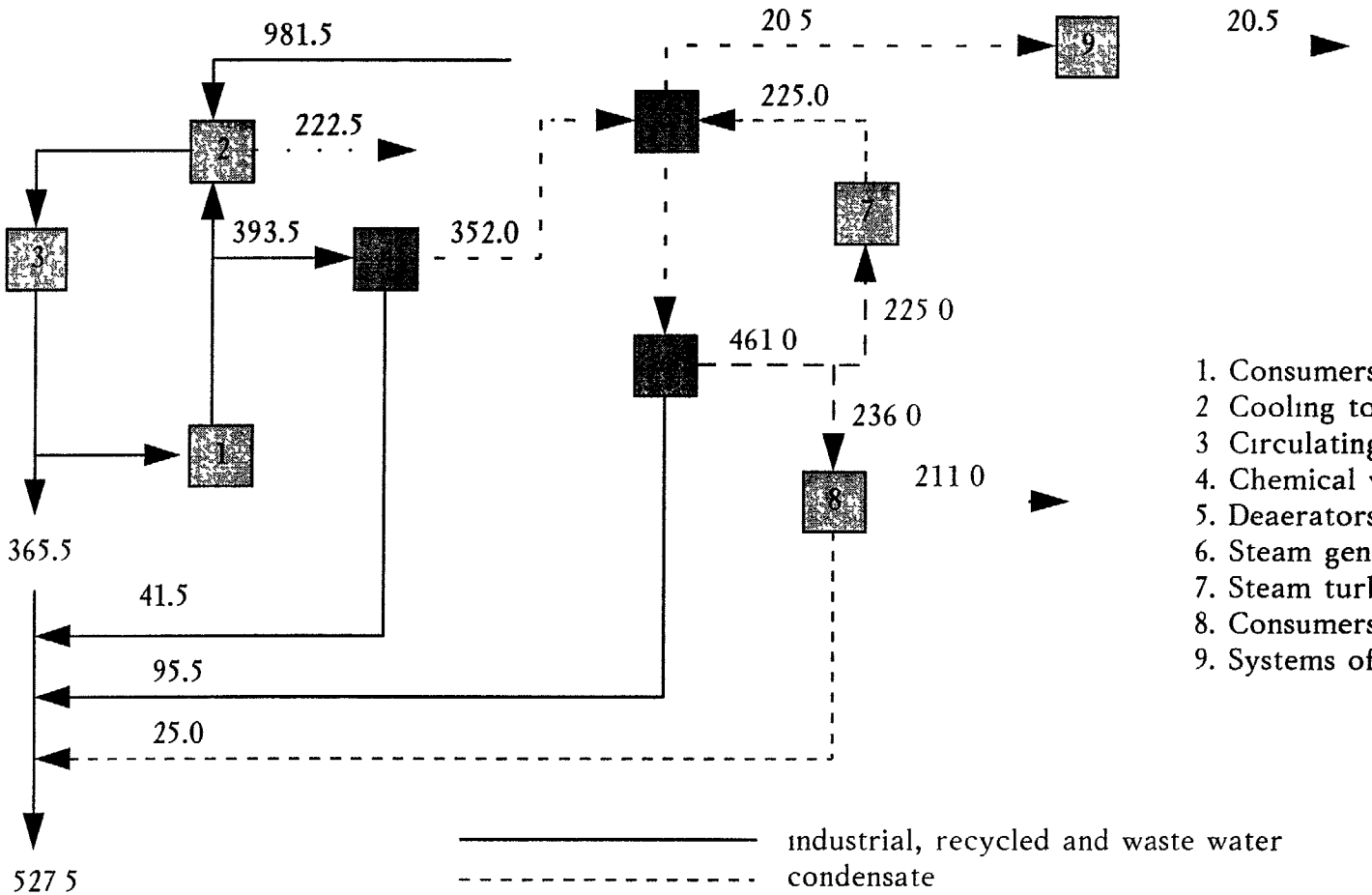
All the water losses in the system are compensated by the fresh industrial water. The consumption of this water is on the average 981.5c.m.per hour. There is a large incentive to capture and recycle much of these evaporative losses It costs the plant 0 49 Grievnas per m^3 fresh water At a monetary exchange rate of 1.86 (Grievnas per U S dollar), this production department is expending 259$/hour in water consumption On yearly basis (assuming 8760 hours of operation) fresh water supply is costing the facility approximately 2,265,049 U.S. dollars. It is recommended that the plant examine technical approaches to capturing these losses, condensing them and recycling them through the system The engineering solutions to reducing these losses are fairly straightforward. A series of condensers and simple steam traps, along with appropriate ducts and transfer lines can be designed.

Oxygen and Agglomeration Shops.

A water balance for these operations is given in Figure 3. Water supply systems of the both shops are interrelated. Total losses amount to 141.5 c.m.per hour and consist of evaporative losses including losses in the cooling towers of the oxygen shops (136.1c.m.per hour) and of the water that is spent on the moistening of the charge in the agglomeration shop (5.4 c.m.per hour). Waste waters (175.7 c.m.per hour) are sent to the cooling pond.

Consumption of the fresh industrial water is 317.2 c.m.per hour. This amounts to about 83.56 U.S dollars in fresh water costs per hour or about 732,016 U.S. dollars on a yearly basis. Again, the plant has a large incentive to capture and recycle a portion of these losses. A major area of upgrading is in cooling tower operations which appear to be more than 40 years old and in need of major repairs The plant should specifically examine the water nozzle injection system to ensure maximum droplet interfacial area for cooling purposes If the heat transfer characteristics of evaporative cooling from these towers can be enhanced, there are likely significant savings in water consumption through more efficient thermal contact area

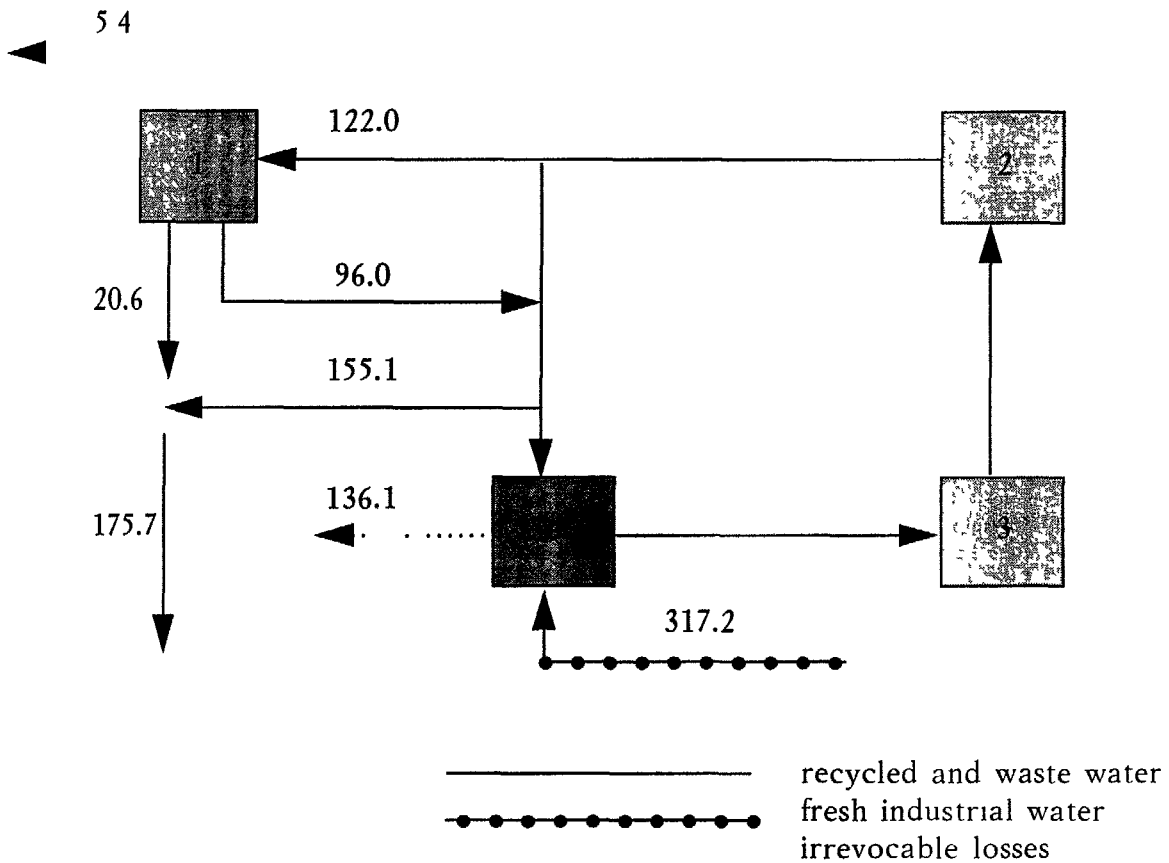
Figure 2. **Material Balance of the Water Consumption and Water Discharge of the Central Heating and Power Plant - Gas Vapour System**



1. Consumers of the water of the turbine shop.
2 Cooling towers.
3 Circulating pumping unit.
4. Chemical water purification.
5. Deaerators.
6. Steam generators.
7. Steam turbines.
8. Consumers of vapour.
9. Systems of evaporative cooling of the furnaces.

industrial, recycled and waste water
condensate
chemically purified and feed water
steam
irrevocable losses

Figure 3. **Material Balance of the Water Consumption and Water Discharge of the oxygen and Agglomeration Shops.**



1. Consumers of water of the agglomeration shop.
2. Consumers of water of the oxygen shop.
3. Circulating pumping unit.
4. Cooling towers.

Blast Furnace Shop.

Irrevocable losses associated with cooling operations at the blast furnaces and pouring equipment amount to 51 0 c.m per hour Because of the nature of these operations it is likely not practical to capture these losses.

Water from the cooling pond is supplied in great quantities (3997 0 cm per hour) The amount of water discharged into the pond is 3946 0 cm per hour The recycling system that supplies water for air scrubbing purposes also has significant losses Typically 92 0 cm per hour is lost due to evaporation along with condensed losses in the units of wet gas scrubbing (62 0 cm per hour), and also by evaporation from the surface of radial settlers and pans (30. 0 cm per hour). System blowdown amounts to 573.0 cm per hour and consists of losses from the sludge directed to the sludge pond (283.0 cm per hour) and an overflow of 290.0 cm per hour that is sent to the cooling pond. The loss of water in the system is about 665.0 cm per hour which is made up for by water from the cooling pond.

Gas scrubbing catch dust is handled as a sludge and is deposited in the sludge pond. The quantity of sludge is 30.25 tons per hour. The main components of sludge are Fe_2O_3(74.5%) and CaO (12%) The sludge is rich enough in iron oxides to warrant a study on recovery. This would amount to about 197,000 tons of iron oxide that could be recycled through the system and represents a savings of about 1.31 million U S dollars Water losses alone represent another 212,312 U S dollars per year in potential savings It is recommended that the plant conduct a feasibility study to assess technical options for reducing the water losses and recycling the iron oxides to the converter shop.

Oxygen Converter Shop.

From the recycle system, 526 0 cm per hour of clean water to the oxygen converter shop is diverted which is then used for the needs of the tar - bonded dolomite (140 cm per hour) and lime-burning (100 cm per hour) departments, and also for the makeup of the recycling of gas cleaning facilities(286 cm per hour) The compensation of the recycled water losses is carried out by fresh industrial water (120 0 cm per hour), and also from the cooling pond (409.0 cm per hour.)

Irrevocable losses of water amounts to 68.0 cm per hour in the recycle system of gas cleaning operations for the oxygen converter shop. These losses include evaporation during gas scrubbing, from the water surface of ponds and from settling basins (59.0 cm per hour) and also by quenching of the converter slag (9.0 cm per hour.)

The losses of water from the sludge amounts to 218.0 cm per hour. The compensation of losses is carried out by blowing clean water (286.0 cm per hour) to the system.

The sludge that goes to the sludge pond is 8 33 tons per hour on a dry basis. The basic components of this sludge are Fe_2O_3 (79%), CaO (9.2%) and MgO (1.5%). Again, the sludge is high in iron oxide content and represents about 58,000 tons per year of recyclable material that is worth approximately 385,000 U.S. dollars. Water losses represent another 277,000 U.S. dollars per year. Based on the water loss revenues from the oxygen converter department and those from the blast furnace operation, these are nearly 490,000 U S dollars in potential savings. The facility should seriously examine replacing wet scrubbing operations with dry gas cleaning technology Although the engineering has not been scoped out it is the author's opinion that such an investment would be payed back in savings in under two to three years.

Rolling Mill Production.

The total amount of water supplied to the rolling shops from the cooling pond is 13070 cm per hour and fresh industrial water-94 cm per hour

Approximately 2927 5 cm per hour of heated unpolluted water is taken to the cooling pond and 10228 cm per hour of water after the settlers Irrevocable losses of water from evaporation and with scale are 8 5 cm per hour

Scale and oils are production wastes The total amount of scale captured by the pollution control facilities are 86700 tons per year and the amount of oils is about 150 tons per year The scale captured by the pollution control facilities then goes to the agglomeration plant where it is added to the charge for the production of agglomerate.The concentration of iron in the scale is 66-71%, oil - 8%, water - 4-14%. Again there are significant potential savings associated with the sludge recycling, to which the plant has recognized and is recycling about 87% (or 90 tons per year) of the iron oxide and another 73% of the oil The rest of the scale and oils are discharged into the plant cooling pond This incremental amount may be worth capturing but the economics should be closely examined.

Processing of the Metallurgical Slag.

Irrevocable losses in the recycling system of the water supply to the granulation installation are 195 cm per hour, including losses from evaporation and with the moisture carried off by granulated slag (135 cm per hour) The consumption of quenching water for slag is 60 0 cm per hour The loss of water is compensated by water from the plant cooling pond

Noted earlier, the recycled water for gas cleaning in the oxygen converter shop is used for quenching converter slag (9.0 cm per hour)

The total amount of slag is:

- blast furnace slag - 252,000 tons per year
- converter slag - 173,000 tons per year.

Total water losses in this part of the plant amount to 450,000 dollars per year. There is more than enough incentive to examine conservation and recycling options.

Additional Productions.

The fresh industrial water and the water from the cooling pond are used for the water supply of additional productions.The total consumption of the fresh industrial water is 47.0 c.m. per hour. Irrevocable losses amount to 0.5 c.m. per hour. The waste water goes to the cooling pond. The water consumption from the cooling pond is 49 0 cm per hour The loss of recycled water is insignificant.

OVERALL WATER BALANCE FOR THE FACILITY.

Water consumption by the subject facility is based on sources from a By-Product Coke Plant,

fresh surface water, and a highly inefficient recycling operation

Waste waters from a By Product Coke Plant go from the sludge pond along with purified waters of the Enakievo Metallurgical Plant The accumulation and partial purification of drainage water containing mercaptans are carried out in the cooling pond and in an aeration pond Water from these sources go to the cooling pond are used to offset the losses

The material balance of the cooling pond and other hydro economic constructions that are located outside the perimeter of the plant's property are given in Figure 4.

An overall water balance fot the plant is given in Figures 5A and 5B . As shown, the total amount of the plant waste waters discharged through the four sources into the Bulavin River is 1252 cm per hour

Fresh industrial water is the primary source of water loss compensation. This water is a mixture derived from the Severski Donets- Donbass canal and the Volintsevske Reservoir Consumption is 1560 cm per hour, or roughly 3.6 million US dollars per year in cost to the facility. The plant is currently not looking at conservation options and is strongly urged to begin examining pollution prevention options The current thinking among management is to look for cheaper sources of water supply, rather than to invest in a pollution prevention and aggressive recycling programs that would conserve water. As an example, the plant management is conducting a feasibility study to construct a multi - million dollar water treatment plant to clarify acid mine drainage water Their argument for this project is that they can reduce the unit cost of water supply The plan has gone before the Oblast Administration but is stalled because of a lack of funds. The plant study does not address the economics of the treatment plant, specifically there is no definition of the return on investment and no comparison to alternate approaches such as replacement of wet gas scrubbing operations

There are roughly 255,000 tons of recyclable sludge that represents about 1.7 million U S. dollars This is a significant recycling opportunity that should be studied in detail. In addition to this, the existing sludge pond is estimated to contain between 5 and 6 million tons of iron oxide rich sludge The recovery of this material is likely more expensive and will require a complex recovery scheme because it is contaminated by various sources including the By-Product Coke Chemical Plant. Still, there is up to a 40 million dollar incentive to capture from this resource and the plant should implement a detailed study to assess potential recovery techniques and their economics At the very least, the plant should perform an assay of the metals concentration in this sludge deposit.

Figure 4. **Material balance of the cooling pond and other hydroeconomic installations**

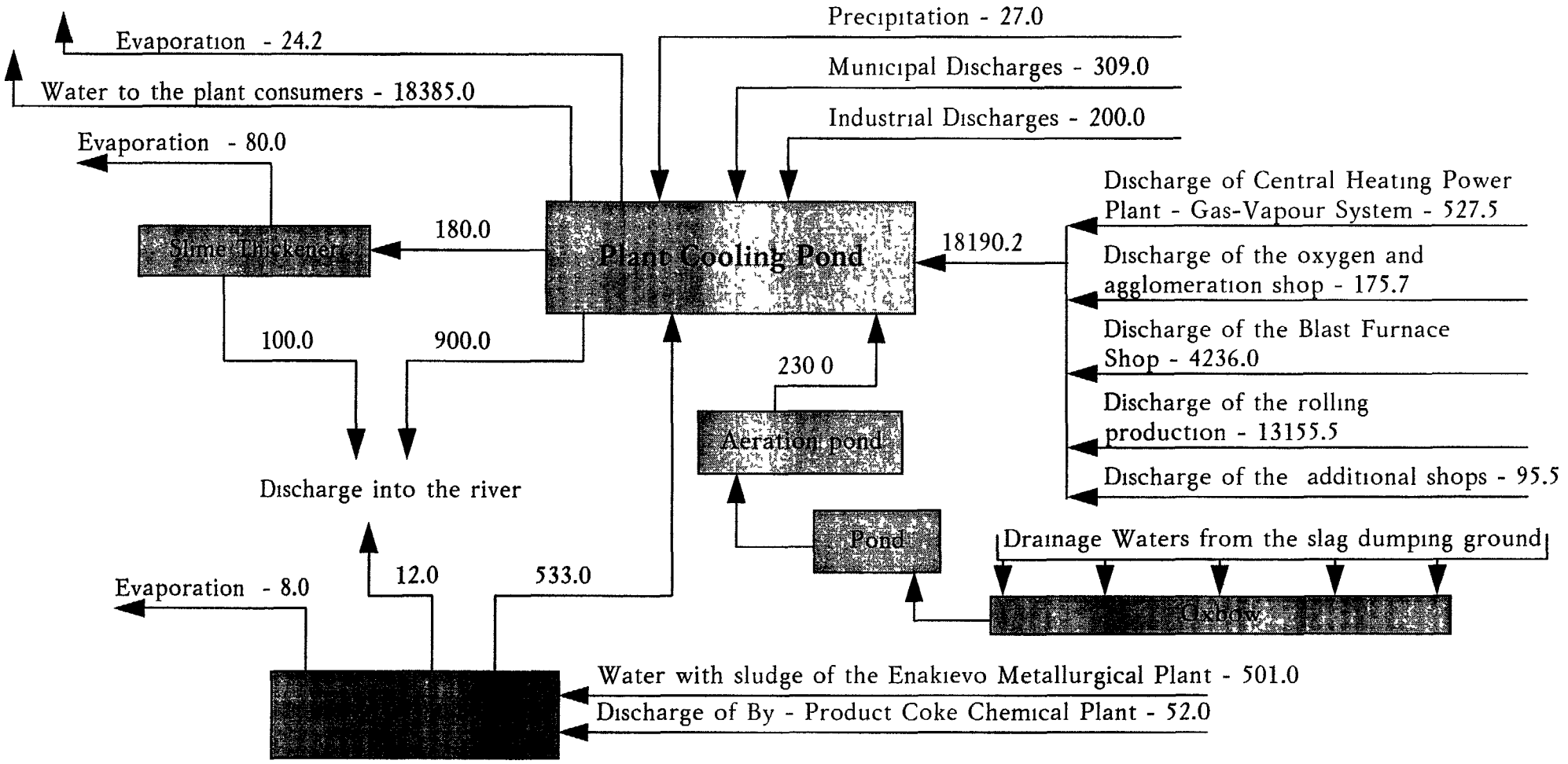
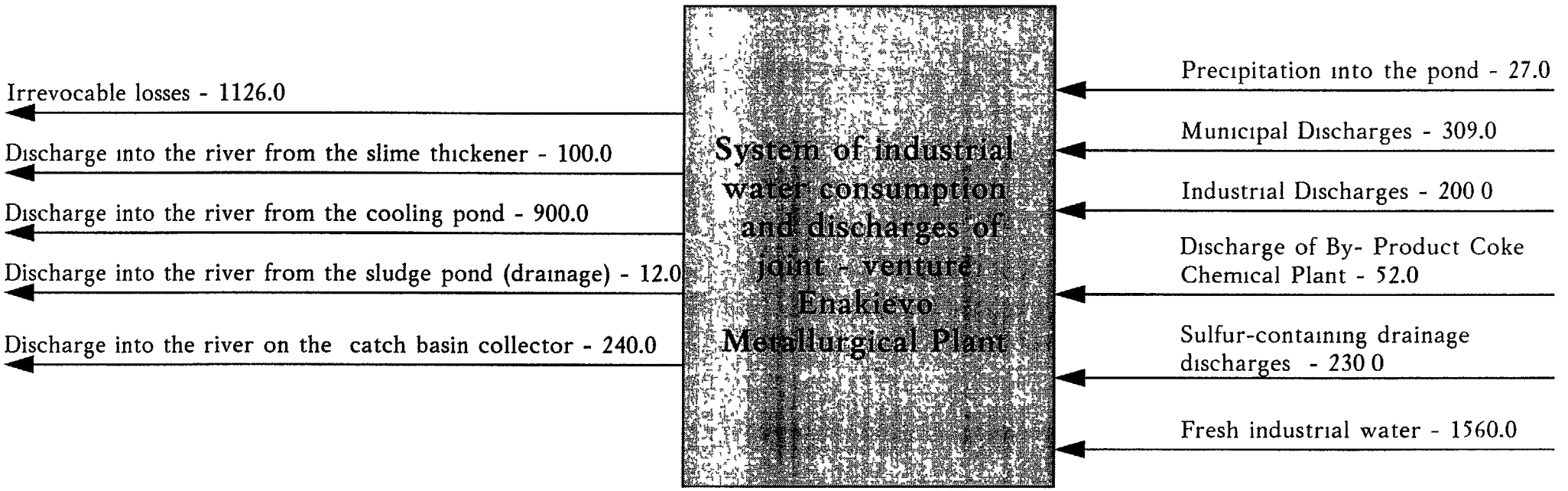


Figure 5A.

Material balance of the water consumption and Discharge in the whole of the plant



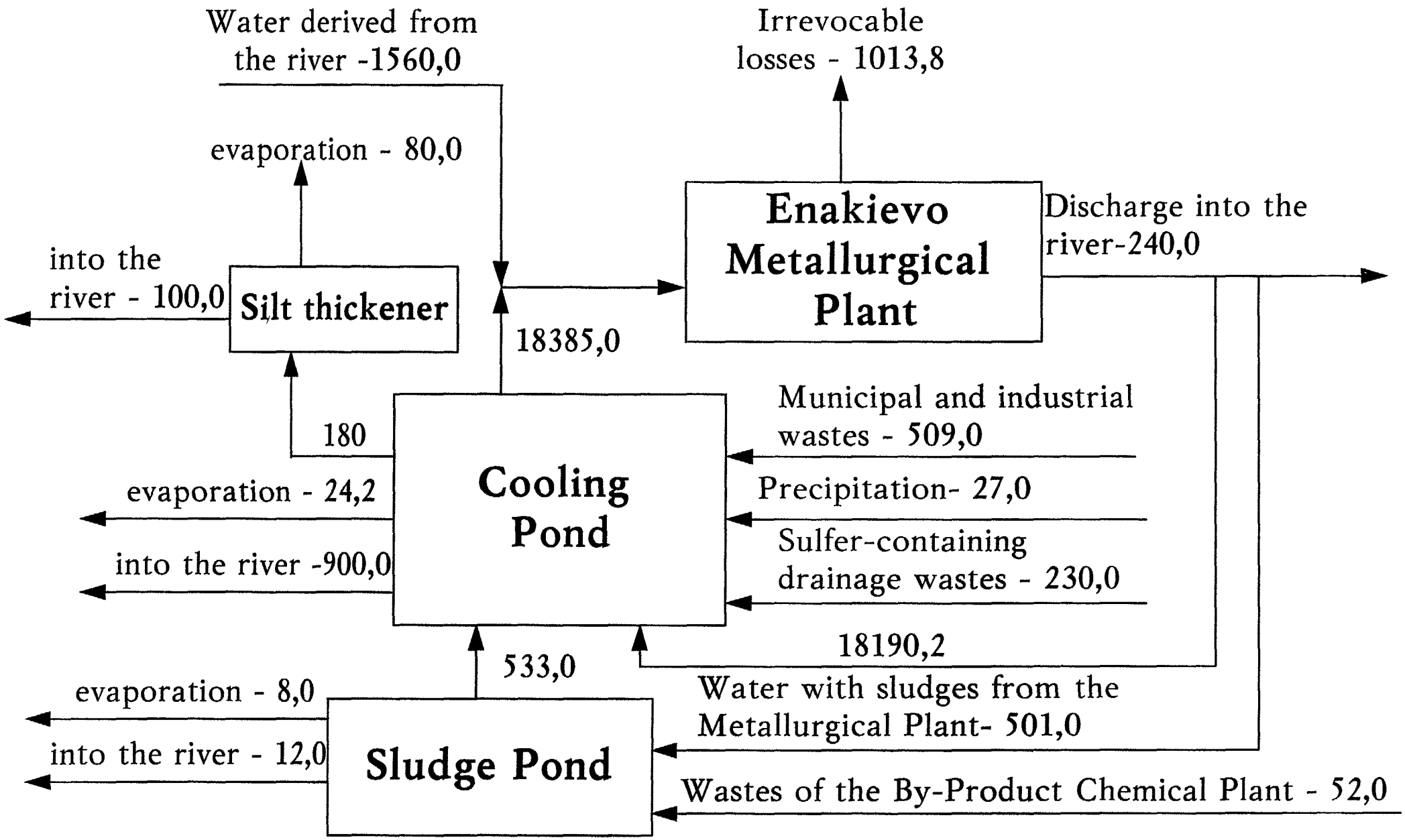


Figure 5B. **Material Balance of the Water Consumption and Drainage for Enakievo Metallurgical Plant (m^3/hour)**