Environment Protection Engineering

Vol. 10 1984 No. 1

GRAŻYNA KMIEĆ*

EFFECT OF COOLING TOWERS ON THE METEOROLOGICAL SITUATION IN THE IMMEDIATE VICINITY AND ON THE CHEMICAL COMPOSITION OF ATMOSPHERIC PRECIPITATION

The objective of the study was to determine the effect of cooling towers on the meteorological conditions and the combined environmental impact due to the interaction between cooling tower plumes and emissions from power-plant stacks. Particular consideration was focused on the downwash of pollutants from the atmosphere which penetrating into soil are responsible for the variations in soil and aquatic environment acidity, as well as for the corrosion of structural elements and deposition of impurities in the immediate vicinity of the tower.

1. INTRODUCTION

The environmental impact of cooling towers used as heat rejection equipment in large coal-fired power plants has become recently a problem of great concern. It has been stated that many different processes occurring in the atmosphere contribute to some unfavourable changes in the chemical composition of rainwater and snow, thus affecting agricultural production. That is why there are numerous reports on the environmental impact of cooling tower plumes. There are two basic problems concerning the operation of cooling towers, i. e. emission of water vapour and rejection of waste heat. The cooling tower plumes of small power plants have only a slight effect on the relative air humidity. The increased fog or icing potential in the immediate vicinity, even though troublesome, can be considered as being negligible. This is not so in the case of large power plants the number of which rapidly increases. Thus, the direct and indirect effects of the cooling tower plume and drift deposition should be at least partially determined and mathematical models are required to describe the potential overall environemental impact. A consi-

* Institute of Environment Protection Engineering, Technical University of Wrocław, 50-370 Wrocław, pl. Grunwaldzki 9, Poland.

derable effort has been made over the past few years to increase our understanding of the cooling tower plume problem. In these papers attempts have been made to estimate this impact qualitatively as well as to construct quantitative mathematical or laboratory models [7].

2. EFFECT OF COOLING TOWERS ON ATMOSPHERIC PHENOMENA

Cooling tower drift and its potential environmental impact have become recently a problem of serious concern, because cooling towers are generally used as heat rejectors in large plants. The main task of the cooling system is to reject heat from the condensed water vapour. Water vapour may be cooled in the condenser with running water (open system) or with recirculated water, which in turn is most frequently cooled in wet cooling towers with natural draught (closed system). Atomized hot water supplied through nozzles is cooled in a direct contact with atmospheric air. There are three methods by which the water temperature in a cooling system can be decreased:

1) evaporation of some part of the water at the cost of heat produced by the drop in the internal energy of the cooling process,

2) convectional rejection of heat received by air,

3) addition of cold water.

Hot air saturated with water vapour is released to the atmosphere. Thus, during one hour, a 1000 MW power plant rejects about 2200 Mg of vapour a condensation heat of which is 6280×10^6 kJ. Heat and mass exchange between water and air occurring in the shell of the cooling tower [7, 8] gives a mixture of air, water vapour, and water aerosol. The temperature of such a mixture is often higher than that of the ambient air. While leaving the cooling tower outlet with a high speed, the water vapour stream mixes with atmospheric air; consequently, the temperature drop is followed by further recondensation of a certain portion of the vapour contained in the stream. In this way the visible (condensed) part of the cooling tower plume (referred to as visible plume) is formed. Under certain conditions, the visible plume may reach the level which is known as natural convection. In this particular case it can happen that the plume is transformed into a cloud able to spontaneous vertical growth. Plumes released from small cooling towers are subject to prompt mixing with the ambient air, so they evaporate almost completely before reaching the natural convection level.

The cooling tower plume consists also of an invisible portion (referred to as invisible plume), which is due to the lower temperature of the plume compared with that of the ambient air. The invisible plume of an increased humidity continues to descent until the hydrostatic equilibrium with the immediate environment is achieved. Thereupon it is dispersed by turbulent diffusion. There are also some other components in the cooling tower plume: the so-called recondensate and drift droplets. The latter are formed by mechanical and aerodynamic forces, and the former result from thermodynamic processes, i. e. from the recondensation of water vapour. The sizes of droplets may vary from small

(1–20 μm for recondensate droplets) to large ones (40–110 μm for drift droplets). Deposition rates depend mainly on large droplets since they reach ground level (or the existing objects) closer to the cooling towers than the smaller droplets do. The problem becomes serious when water with an increased concentration of salts is used for cooling, since then distinct concentration nuclei may be formed and affect substantially the mechanism governing the natural precipitation from convection clouds.

3. EFFECT OF THE VISIBLE PLUME ON THE IMMEDIATE VICINITY OF THE COOLING TOWER

Under certain conditions, which depend on the atmospheric equilibrium and on the initial parameters of the plume, the cooling tower is a factor initiating the formation of a cloud similar to a natural convection cloud. When clouds of that type are formed permanently in the same spot, the amount of precipitation will increase locally within the distance of several to over a dozen kilometers downwind from the cooling tower. This distance is determined by such meteorological factors as: relative air humidity, air temperature, and wind speed. For example, at low relative humidity and high air temperature, the plume evaporates quickly. If, however, wind speed is low, while relative air humidity and air temperature are high, a very dense plume will be formed and may extend over the distance of several kilometers.

Wind speed may affect the environmental impact of the cooling towers in two ways: it brings about an accumulation of water vapour which accounts for the occurrence of drizzle and influences the motion of humid air masses ejected from the cooling tower (the higher the wind speed, the lower the height of the plume). At high wind speeds, the density of the water vapour becomes sufficiently weak to decrease the fogging potential. The aerodynamic effect of the wind and drift magnitude depend also on the structure and dimensions of cooling tower and associated objects, on the surface roughness and configuration of the adjacent area. It is reported [8] that a twofold increase in the power of electric power plants accounts for the extension of the visible plume by about 40%. A classification of the visible plume according to its length is given in tab. 1 [1].

The classification was based on results obtained from 717 observations. An experimental study of plume phenomena becomes difficult, especially when several cooling towers are in operation, because individual plumes are overlapped from one combined plume. Independent plumes released from single towers are much shorter.

Overcamp and Hoult [3], who investigated the interaction between a plume and natural clouds producing rainfall, have found that the residence time of droplets in the plume was substantially shorter than the time required for rain drop formation. When the plume approaches the ground level, the drizzle phenomenon is intensified being even as intense as 1 mm/h. The amount of precipitation received in this area depends on relative air humidity. Quantitative variations in drizzle with the distance from the cooling tower have been stated by observations; the maximum being found at the distance of 200 to 400 m from the emission source. This distance was determined from the ratio of wind speed to the time of deposition of the droplets from a given height of the tower. The most frequently observed direct environmental impact of the visible plume is manifested in decreasing solar radiation and the deposition of water or icing within the area where the plume is in contact with the soil. The process in question may lead to significant changes of the microclimate within the affected area and, consequently, to the changes in conditions of agricultural production. A special hazard associated with deposition of droplets in the vicinity of the tower is due to sulphur compounds emitted from the power plant stacks, as they intensify corrosity and some biologically adverse effects of acid rains.

Table

Classification of the visible plume according to its length with respect to relative air humidity

Klasyfikacja smugi widzialnej pod względem jej długości w odniesieniu do względnej wilgotności powietrza

Relative air humidity %	Length of plume		
	Short 300 m	Medium 300–900 m	Long 900 m
low, 75	46	2	0
moderate, 75–90	10	13	11
high, 90	3	3	15

4. INFLUENCE OF THE INVISIBLE PLUME WITH VARIABLE HUMIDITY

The invisible plume (which is also referred to in the literature as the dry portion of the cooling tower plume) results from evaporation of visible plume and is characterized by an increased humidity. After having reached the state of hydrostatic equilibrium (e. g. near the ground level, the humidity of the invisible plume is in most instances higher than that of the ambient air. The impact of the invisible plume is especially noticeable in the structure of the cloud deck and atmospheric precipitation. If in stable air conditions an increased humidity may stimulate cloud formation (producing a population of strato-cumuli) or mist, then under unstable conditions the structure of convection clouds may be changed bringing about intermittent precipitation [7].

American reports on the Keystone Power Plant show that this area receives an increased amount of precipitation due to the operation of cooling towers (the precipitation from natural clouds induced rather by the interaction between cooling towers and natural clouds than by the operation of the cooling towers as a source of water vapour emissions).

Another problem of serious concern is the interaction between the plume and the flue gas stream emitted from the smokestack of the power plant. When high sulphur coal is burnt for power generation, the overlapping two plumes may contribute to the removal of SO_2 from the air, but at the same time it can give rise to the potential hazard of highly contaminated rain- or snowfall.

5. WASHDOWN OF AIR-BORNE POLLUTANTS THROUGH ATMOSPHERIC PRECIPITATION

Since the behaviour of the cooling tower plume depends on meteorological factors, it is possible to distinguish the following forms in which the pollutants appear and interact with water vapour emitted from cooling tower [5]:

1. Pollutants as natural components of the cooling tower water that have not been removed during its treatment,

2. Adsorption of gaseous pollutants and particulates during the contact of cooled water with polluted air in the shell of the cooling tower,

3. Reactions occurring between the water vapour plume released from the cooling tower and the flue gas stream emitted from the smokestack and deposition of pollutants into the soil and water reservoirs through rain- and snowfall.

Having in mind the increasing demand for electric power, it may be expected that the processes referred to as 2. and 3. will create serious environmental hazards.

In rainwater samples the following compounds and parameters have been determined: ammonia nitrogen, nitrate nitrogen, sulphur compounds, chlorides, calcium, sodium, phosphorus, magnesium, carbonates, pH, and alkalinity. Water vapour in the atmosphere condensates on aerosol particles. The highest concentrations of pollutants in water were found to be due to convection clouds. Water droplets that are condensed from the water vapour plume incorporate a certain quantity of pollutants contained in the cooling water. These droplets before entering the soil must pass through a layer of more or less polluted air. Chemical composition of droplets is subject to variations — the total concentration of water pollutants increases. The fact that the absorption processes are occurring in the atmosphere is evidenced by the difference in chemical composition of cloud droplets and water samples collected on the ground surface [6]. Increased concentrations of sulphates (absorption of SO_2 and oxidation of sulphites to sulphates) and nitrates (absorption of nitrogen oxides and oxidation of ammonia nitrogen) have been observed in rainwater samples. The washdown of airborne dust particles was accompanied with the increase of calcium compounds in the rainwater. At the same time pH and conductivity increased. The washdown of air pollutants through rain- and snowfall was estimated from the decreasing concentrations of pollutants in the atmosphere. This process is influenced by: the duration and the intensity of rain- or snowfall. BEILKE and GEORGII [2] described the relationship between the decrease of atmospheric SO_2 and the duration of rainfall. ZA-

Lewski [9] determined the influence of rain intensity on the variations of pH and on NO_2 and SO_2 concentrations in rainwater samples. Thus, the results reported [2, 9] may be of great help in determining the washdown of pollutants by a cooling tower plume.

To determine the contribution of the cooling tower plume to the pollution of rainwater, preliminary measurements were carried out in a twelve-point system located in the vicinity of an Upper Silesian power plant fired with bituminous coal [5]. One of the measuring points was taken as a reference (background). The other measuring points were located in the predominant wind direction.

The average amount of precipitation received by the area under a direct impact of the cooling tower plume is 10–30% greater than that measured in the background area. The measured average concentrations of sulphates, chlorides, calcium, and magnesium increased 2.6, 3, 3.6, and 3.3 times, respectively, as referred to the background. Insignificant variations in pH of precipitation water are most likely due to the neutralization of solution by calcium compounds contained in the fly ash emitted from the power-plant smokestack (calcium and aluminium concentrations in dust fallout depositions were 11.3% and 12.5%, respectively). The annual dust fallout deposition for the twelve measuring points varied from 214 to 435 $t/km^2/year$ exceeding in most cases the maximum admissible level being 250 $t/km^2/year$. Chemical composition of the deposited dust has proved its stack emission origin. Humidity measured in soil samples ranged from 14% to 18% for top soil and from 12% to 16% for 50 cm deep soil layers extending in the direction of prevailing winds. Vegetation (grass) samples showed the increasing concentrations of calcium, magnesium, fluorine, iron, and zinc, as compared to the sampling material collected in the background area.

It seems that the data obtained, as well as the reports published by other workers, show that attempts should be made to determine quantitatively the environmental impact of cooling towers.

6. CONCLUDING REMARKS

Both measured results and literature data indicate that while determining the cooling-tower impact on the natural environment, the technical parameters of the cooling tower, the atmospheric and local conditions (e. g. surface roughness, regional climate etc.) should be taken into account. It may be expected that although cooling towers to be built will include drift suppressors and that the visible plume will rise vertically (thus contributing to the abatement of the fogging and icing potential), nevertheless there will occur some undesirable meteorological effects, such as disturbances in the cloud deck, in the amount of precipitation received in this area, and in the chemical composition of precipitation water.

The environmental impact of cooling towers requires long-range investigations including the following main problems:

1. Application of the existing numerical models or the development of modified model for the visible and invisible parts of the cooling tower plume; the verification of these mo-

dels based on the observations. Models of that type can provide information concerning the shape and the area affected by parts of the plume as well as the variations of humidity under different meteorological conditions.

2. Determination of the interactions between smokestack emissions and cooling-tower plumes.

3. Measurements and observations of the atmospheric precipitation: analyses of the chemical composition of rainwater, observation of icing and condensation phenomena, comparison of measured results with model simultations and literature data.

REFERENCES

[1] Barber F. R., Martin A. et al., *The persistance of plumes from natural draught cooling towers*, Atm Env., Vol. 8 (1973), pp. 407–418.

[2] Beilke S., Georgii H. W., *Investigations on the incorporation of sulfur dioxide into fog and air droplets*, Tellus, No. 3 (1968).

[3] *Environmental consequences of wet aircooliers*, Seminar on environmental aspects of the cooling systems of the thermal power stations, Zurich 1974.

[4] Haman K., *Wpływ chłodni kominowych na zjawiska atmosferyczne w rejonie kombinatu paliwowo-energetycznego ,,Bełchatów''*, Papers of the Institute of Geophysics, University of Wrocław.

[5] Pacyna J., Kmieć G., Kukliński A., *Wpływ chłodni kominowych elektrowni dużych mocy na środowisko*, Report, Series SPR No. 14/80, Technical University of Wrocław.

[6] Petrenczuk C. P., Drozdowa W. M., *O chimičeskom sostavie oblačnoj vody w niekotorych rejonach E.T.S.*, Trudy Gl. Geof. Obs., wyp. 85.

[7] *Studium ochrony środowiska w rejonie elektrowni i kopalni ,,Szczerców''*, part II, Papers of the Institute of Meteorology and Water Management, 1973.

[8] Szabo E., Idojaras, J. of the Meteorological Service, Vol. 82 (1978), No. 2, Budapest.

[9] Zalewski J., *Wpływ zanieczyszczeń atmosfery na wody opadowe*, Pr. SiW PW. 1971, Papers of the Institute of Meteorology and Water Management.

WPŁYW WIEŻ CHŁODNICZYCH NA WARUNKI METEOROLOGICZNE ORAZ SKŁAD CHEMICZNY WÓD OPADOWYCH

Przedstawiono wpływ chłodni kominowych na atmosferę oraz współoddziaływanie smugi pary wodnej z emitowanymi z elektrowni zanieczyszczeniami. Szczególną uwagę zwrócono na wymywanie zanieczyszczeń z atmosfery i przechodzenie ich wraz z wodą do gleby. Zjawiska te powodują w środowisku człowieka zmiany takie jak: podwyższenie kwasowości gleby, wahania w wartościach pH w zbiornikach wodnych lub większą korozyjność elementów konstrukcyjnych.

DER EINFLUß DER KAMINKÜHLTÜRME AUF DIE METHEOROLOGICHEN VERHÄLTNISSE UND AUF DIE NIEDERSCHLAGSWASSERZUSAMMENSETZUNG

In dieser Veröffentlichung werden die Effekte besprochen, welche in der Atmosphäre auftreten, die durch die Tätigkeit der Kaminkühltürme sowie durch die Miteinwirkung des Wasserdampfstreifens und den emitierten Kraftwerkverunreinigungen hervorgerufen werden. Besondere Aufmerksamkeit wurde

auf die Verunreinigungsauswaschung aus der Atmosphäre und ihren Übergang mit den Gawässern in den Boden gerichtet, was eine ganze Reihe von Änderungen der Menschenumwelt verursacht. Folgende Parameter ändern sich dadurch: Ansteigung der Bodenazidität, pH-Änderungen in Wasserbehältern und Anteigung des Korrosionsgrades des Konstruktions-Elementes.

ВЛИЯНИЕ ОХЛАДИТЕЛЬНЫХ БАШЕН НА МЕТЕОРОЛОГИЧЕСКИЕ УСЛОВИЯ И НА ХИМИЧЕСКИЙ СОСТАВ АТМОСФЕРНЫХ ОСАДКОВ

Рассмотрено влияние башенных охладителей на атмосферу, а также взаимодействие струк водяного пара с выбрасываемыми из электростанции загрязнениями. Особое внимание уделено вымыванию загрязнений из атмосферы и переходу их вместе с водой в почву. Эти явления вызывают в человеческой среде такие изменения, как: повышение кислотности почвы, колебания в значениях pH в водоёмах или большую коррозионность конструктивных элементов.