COOLING WATER DISCHARGE INTO THE IMPOUNDMENT RESERVOIR VIENNA-FREUDENAU: EVALUATING DIFFUSER PERFORMANCE AND CORMIX-BASED MIXING SIMULATION

Bernhard H. Schmid[1]

[1]Institute of Hydraulic and Water Resources Engineering, Vienna University of Technology, c/o Vegagasse 16, A-1190 Vienna, Austria
phone: +43 1 3688623; fax: +43 1 3688623; e-mail: schmid@hydro.tuwien.ac.at

ABSTRACT

In the wake of the construction of the River Danube hydropower plant Vienna-Freundenau the cooling water discharge of the Donaustadt thermal power plant was redesigned, with the associated mixing simulations performed by means of CORMIX, the CORnell MIXing zone expert system. Particular attention had to be paid to an ecologically sensitive zone in the receiving Freudenau impoundment reservoir, comprising the fish pass of the Freudenau hydropower plant, which was (and is) located on the same (left) bank of the River Danube as the Donaustadt thermal power station. To achieve a reliably high initial dilution of the cooling water, a unidirectional multiport diffuser was chosen to be installed, a decision which consequently resulted in the first construction of a cooling water diffuser in Austria. This diffuser now discharges up to 20 m³/s of cooling water into an impounded reach of the River Danube with a water depth of some 11 m. Injection is co-flowing in plan view and oriented 45° upwards. The diffuser comprises two feeder pipes with 16 nozzles each, giving a total of 32 discharge ports, equally spaced at a hydraulically effective distance of 2 m (with 62 m, therefore, between first and last discharge port centreline). CORMIX-based mixing simulations indicated that the Freudenau fish pass would not suffer heating in excess of 0.7 °C even under adverse conditions (Danube River low flow of 830 m³/s combined with full operation of the Donaustadt cooling water system, i.e. maximum permitted discharge of 20 m³/s and a heating span of 10 °C).

To evaluate the performance of the cooling water diffuser under operation conditions, a thermal monitoring programme was implemented. The recorded data sets were used to compare simulated and measured temperature values downstream of the discharge. The study reported here showed clearly that the cooling water diffuser performs very well indeed, even to a degree that made quantitative comparison of simulated and measured induced excess temperatures difficult, due to the very small temperature rises encountered during the monitoring period.

Although induced excess temperatures kept close to the detection limit for much of the monitoring interval, it was possible to identify data suitable for CORMIX (module 2) validation, nevertheless. In that situation Danube River flow amounted to 1052 m³/s, which is between low and mean flow conditions. The Donaustadt plant discharged 17.2 m³/s of cooling water at a temperature 10 °C above that of the ambient river water. At the inflow section of the fish pass (2.03 km downstream of the diffuser) an induced temperature rise of 0.2 °C was recorded, and the CORMIX 2 simulation of this buoyant mixing process indicated that a temperature increase by 0.18 °C was to be expected. As the temperature sensor gave values with a resolution of one digit (0.1 K) only, it can be concluded that recorded and simulated diffuser-induced excess temperatures matched very well.

Keywords: buoyant jets, cooling water, multiport diffuser discharges, CORMIX

1 INTRODUCTION

The cooling water of the thermal power plant Donaustadt in Vienna, Austria, was originally discharged into an unimpounded reach of the River Danube by means of a surface discharge of capacity 8.6 m^3/s (Fig.1). Intended upgrading of the thermal plant (requiring an increased capacity of the cooling water system of 20 m^3/s) and the impending construction of the River Danube hydro power plant (HPP) Vienna-Freudenau made the design of a completely new cooling water discharge indispensable.

Fig.1: surface discharge of the Donaustadt cooling water (8.6 m^3/s) prior to the construction of the River Danube hydro power plant Vienna-Freudenau

From the ecological viewpoint the newly planned fish pass of the HPP Freudenau required particular attention, as it was to be (and now is) situated on the same, i.e. left bank of the river as the thermal power plant, with the associated risk of being placed right within the cooling water plume of a potential new surface discharge. For that reason plans of a new surface discharge were dropped, and the option of a multiport diffuser discharge was taken up und pursued further. Design of the diffuser was aided by use of the expert system CORMIX (Jirka and Akar, 1991), a short outline of which is given in the following section.

2 THE CORNELL MIXING ZONE EXPERT SYSTEM: A SHORT OUTLINE

The CORnell MIXing zone expert system, better known as CORMIX, was initially developed for the U.S. Environmental Protection Agency (US EPA) with the aim of putting predictions of mixing processes in surface waters due to steady-state discharges of cooling or waste water (as e.g. needed in the course of Environmental Impact Statements), on a scientifically sound basis without becoming too unwieldy to be practical. CORMIX belongs to the group of length scale models and performs a flow classification after interactive input of the key data of the problem considered. Ambient flow is assumed to be steady (as in this application) or tidally reversing. There are modules for submerged single port discharges (CORMIX 1), submerged multiport diffuser discharges (CORMIX 2, applied here) and surface discharges (CORMIX 3, used to analyse the situation prior to the construction of the diffuser). Methodically, the model is based on the similarity theory for buoyant jets, concepts of hydraulic scaling and the data from numerous laboratory and field measurements. The range of applicability of the model has meanwhile been extended to include sediment density currents as well (Doneker et al., 2004). The so-called length scales mentioned before are needed to express the relative importance of the main hydrodynamic fluxes involved, such as the ratio of discharge versus cross-flow momentum (which influences the tendency towards formation of free as opposed to shoreline attached jets).

The flow classification step is followed by the simulation of the key properties needed to judge the ecological impact to be expected, such as (three-dimensional) distributions of concentration or temperature (here: the latter), and measures of plume or jet geometry like their respective widths and depths. This type of quantitative information is finally derived from algebraic equations used to describe the (steady state) form of the jet or plume trajectory, the dilution and the centreline concentration or temperature for the flow class or zone identified in the classification step.

3 DIFFUSER DESIGN

After numerous CORMIX runs and consultations with interested parties (ranging from the company running the Donaustadt power plant to the authorities regulating navigation on the River Danube) the diffuser was constructed according to the following key data:

- two feeder pipes aligned perpendicular to Danube main flow
- stepwise reduction of pipe diameter from 2.5 to 1.4 m to keep differences in the cooling water discharge from the individual nozzles small
- co-flowing discharge in plan view, vertical orientation 45° upwards
- no fanned arrangement of the nozzles to avoid difficulties in construction
- 16 nozzles on either feeder pipe, thus 32 nozzles in total
- height of discharge port centreline: 151.95 m a. MSL
- (impounded) water surface elevation at discharge site: 161.38 m a. MSL
- hydraulically effective nozzle spacing: 2 m.

Fig.2: Donaustadt diffuser arriving by ship

For reasons of size the feeder pipes (plus risers and nozzles) were delivered in two pieces each, the first one comprising the part of the pipe from the bank as far as the first four risers and nozzles, and the second comprising the remaining 12 nozzles. Fig.2, a photo taken against Danube flow direction, shows two such pieces arriving by ship at the construction site. In the background one can see a temporary dike needed to permit accurate placement of the heavy steal pieces, as well as the former Donaustadt cooling water intake ('tower') later also to be replaced by a new structure.

Fig.3: diffusor piece moved by ship crane

Fig. 3 shows transport of one of the diffusor pieces by ship crane, and this is finally mounted and connected to the new outlet structure (Fig.4).

Fig.4: mounting of second feeder pipe

CORMIX-based mixing simulations (Schmid and Jirka, 1999) indicated that the Freudenau fish pass would not suffer heating in excess of 0.7 °C even under adverse conditions (critical design case: Danube River low flow of 830 m^3/s combined with full operation of the Donaustadt cooling water system, i.e. maximum permitted discharge of 20 m^3/s and a heating span of 10 °C).

4 MONITORING, MODELLING AND COMPARISON

In the course of the thermal monitoring programme sensors recorded temperatures at three points in the impoundment reservoir of the hydro power plant (HPP) Freudenau. One of the sensors was placed far enough upstream of the diffuser to provide a reference value for the water temperature unaffected by the cooling water discharge. Two further sensors recorded water temperatures approximately 2 m below the water surface, with one sensor situated about 175 downstream of the diffuser and the other (the one of major ecological interest here) at the entrance to the fish pass, i.e. at a distance of 2.03 km from the discharge (marked by a red arrow in Fig.5).

Analysis of the recorded water temperature data revealed that, over most of the monitoring period, the thermal signal of the cooling water discharge was hardly detectable, if at all. To put it differently, the cooling water diffuser reliably achieved a high initial dilution and was shown to perform extremely well (Schmid, 2006).

The weakness of the thermal signal, in turn, made it difficult to identify situations that could be used for purposes of model validation, which was among the aims of this study. During the monitoring period the Donaustadt cooling water discharge was operated at respective rates of 8.6 m³/s and 17.2 m³/s, with a heating span corresponding to the permitted maximum of 10°C. Among the data sets collected in the course of the monitoring programme, none, however, showed a River Danube flow rate as low as the 830 m³/s assumed for the design case. Situations characterized by Danube flows around or slightly below 900 m³/s could be identified, but these did not coincide with operating periods of the thermal power plant (and, thus, the cooling water discharge). The clearest thermal signal was finally found for the 14th and 15th of January, 2002, with a cooling water discharge of 17.2 m³/s and a Danube flow rate of 1052 m³/s. The diffuser-related temperature increase amounted to 0.2 °C near the inflow section of the fish pass (Fig.5: red arrow). The cooling water plume was simulated using CORMIX (module 2), and the output for x = 2.03 km from the discharge showed a computed excess temperature of 0.18 °C. Considering that recorded temperatures were given with a resolution of one digit, it may be stated that measured and computed temperature increases were in full agreement.

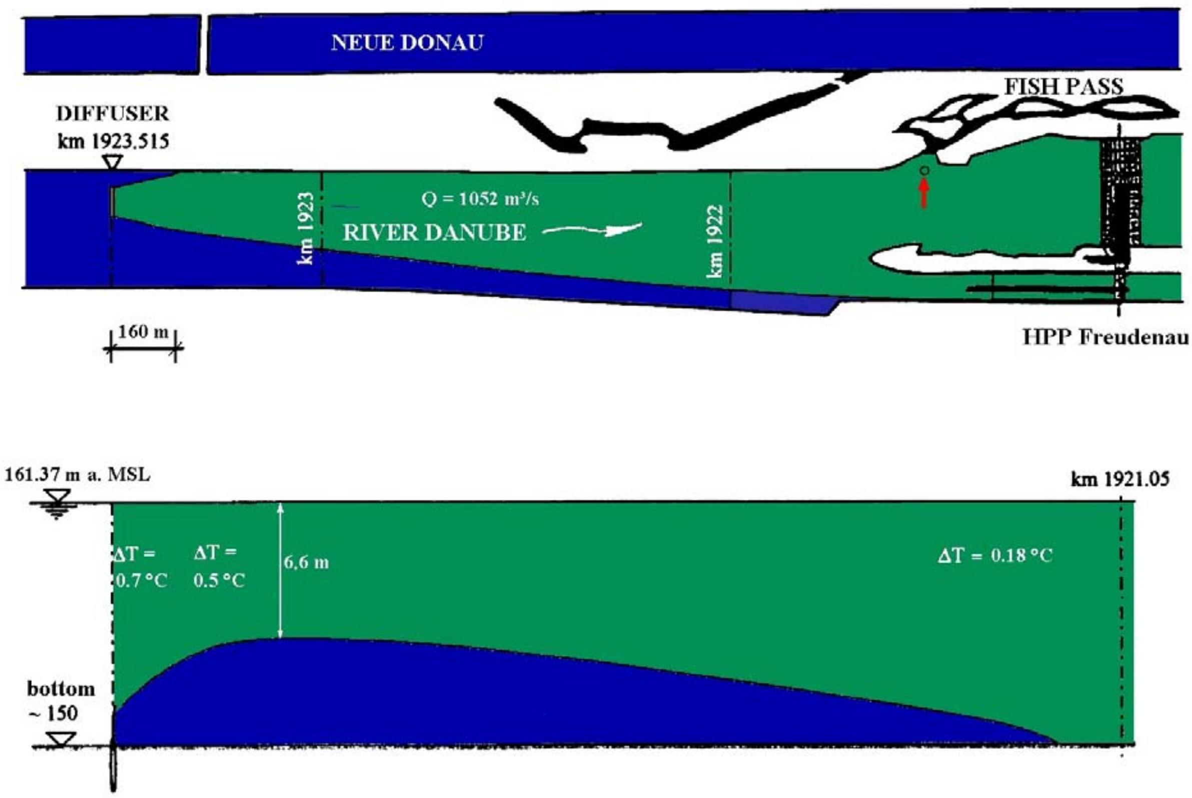

Fig.5: cooling water plume simulated by CORMIX for a discharge of 17.2 m³/s and a Danube flow rate of Q = 1052 m³/s

5 CONCLUSION

The analyses of the data obtained from thermal monitoring in the impoundment reservoir Vienna-Freudenau showed that the diffuser discharging the cooling water of the nearby thermal power plant Donaustadt into the River Danube performed very well. Measured temperature rises due to the operation of the diffuser were found to be very low for most of the monitoring period. A situation characterized by 17.2 m^3/s cooling water discharge (heated by 10°C) and 1052 m^3/s River Danube flow rate was simulated by CORMIX, and recorded and computed temperature increases agreed very closely.

ACKNOWLEDGMENTS

Support received from VERBUND – Austrian Hydro Power A.G. (AHP) is gratefully acknowledged. Particular thanks are due to Dipl.-Ing. Hans Schimpf of Verbund-AHP.

REFERENCES

Doneker, R.L., Nash, J.D. and Jirka, G.H. (2004), Pollutant transport and mixing zone simulation of sediment density currents. J. Hydraul. Engrg. 130(4), 349-359.

Jirka, G.H. and Akar, P.J. (1991), Hydrodynamic classification of submerged multiport-diffuser discharges. J. Hydraul. Engrg. 117(9), 1113-1128.

Schmid, B.H. and Jirka, G.H. (1999), Der Kühlwasserdiffusor des Dampfkraftwerks Donaustadt: expertensystem-unterstützte Planung und Ausbreitungsberechnung (Multiport diffuser for cooling water discharge from the Donaustadt thermal power plant: expert system aided design and mixing simulation). Wasserwirtschaft 89, 238-242 (in German with summary in English).

Schmid, B.H. (2006), Der Kühlwasserdiffusor Donaustadt: Evaluierung anhand des thermischen Monitoringprogrammes (The cooling water diffuser Donaustadt: evaluation using the data from the thermal monitoring programme). Wasser und Abfall 11, 37-41 (in German).