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Integrated conceptual design of heating system at a Swedish mining company

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LKAB Malmberget is a Swedish mining site located at Malmberget, Sweden. Seven boiler centers are located on north part of Malmberget. There are no connections in between these boiler centers, meaning that it is a decentralized heating system. The heat generated is to heat up buildings and for mine ventilation mainly during the cold periods. The heat is mainly provided from electric and oil boilers. However, most boilers under use are over 20 years old, and it is time to retrofit the boiler system and infrastructure. The purpose of this work is to design and optimize the heating system by the integrated concept.
An optimization model based on the mixed integer linear programming (MILP) has been developed to minimize the total heat production cost, including operation cost and investment cost. The model can be used to calculate how a given heat demand can be satisfied at the lowest possible cost. Four different technical options have been considered in a new centralized heating system. On the basis of data input and assumptions, modeling results indicate that a lower cost could be achieved when a waste heat recovery boiler is installed at the old pelletization plant to recover sensible heat from flue gas. This will lead to a remarkable electricity saving (around 70% saving) compared to the reference case. It has also been noticed that in the optimized cases, oil boilers should not be operated due to a higher price compared to electricity, and by estimation an annual reduction of 3000 ton CO_2 and 4.5 ton NO_x could be achieved.

1. Introduction

LKAB Malmberget is a Swedish mining site located at Malmberget, Sweden. The crude ore is first extracted from ore bodies, and then processed through different production units, i.e. sorting plant, concentrating plant and two pelletizing plants, where the final product of iron ore pellet is produced. The iron ore pellet production was 6.5 million ton in 2007.

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The current heating system at LKAB Malmberget is decentralized. Seven boiler centers are located on north part of Malmberget, and there are no connections in between these boiler centers. The heat is used for mine ventilation and heating up building. Most heat is supplied from electric and oil boilers, and some amounts are from compressors and a newly installed waste heat boiler at the pelletization plant, MK3. Totally there are 11 oil boilers and 19 electric boilers located in the different boiler centers. However, most boilers under use are over 20 years old, and it is time to retrofit the boiler system and infrastructure. The purpose of this work is to design and optimize the heating system by using an integrated concept to minimize the total heat production cost.

2. Model design of LKAB Malmberget heating system

2.1 Mathematical model

The method applied in this work is Process Integration. A mathematical optimization model based on mixed integer linear programming (MILP) has been created. The equation editor used is called *Re*MIND, and the commercial software CPLEX is used as the solver. This approach has been applied in iron- and steelmaking and mining fields by our research group. Some descriptions on the approach can be found in our previous work (Larsson and Dahl, 2003; Ryman and Larsson, 2006; Wang et al., 2009).

The objective function can be expressed by the following mathematical term, and the objective is to minimize the total heat production cost,

$$Min \quad \left\{ C_{HS} = C_{Oper,HS} + C_{Inv,HS} \right\} \tag{1}$$

Where, *C*: Cost; *HS*: Heating system; *Oper*: operation cost, e.g. electricity and fuel related cost, environmental cost, personal cost, etc.; *Inv*: investment cost, e.g. equipment cost, maintenance and management cost for boilers and network, etc.

2.2 Boundary, alternatives and input data

The model was created based on 2005 year’s heat production data. The boundary covers 7 existing boiler centers (Denevitz center, Vitåfors center, Alliansen center, BUV center, KOS center, FoU center and CK-lab center) and two pelletizing plant (MK3 and BUV). BUV was started up in the early 1970s, while MK3 is a new pelletizing plant which started operation in 2007. Different with BUV, a waste heat boiler (installed capacity: 5 MW) has been installed at MK3 to recover the sensible heat from flue gas.

The model includes 5 alternatives. First one is to maintain the current decentralized system, and replace old boilers by new boilers. Other alternatives are to build up centralized heating system with consideration of four different technologies. They are: i) Electric boiler center in which an electric boiler will be installed; ii) Peat boiler center; iii) Peat combined heat and power (CHP) center; iv) BUV waste heat boiler center to use the waste heat recovered from flue gas at the BUV pelletization plant. An installed capacity of 5 MW has been applied for each technical option. An efficiency of 85% has been used for oil boilers, peat boiler and waste heat boiler, and assumed efficiency for electric boilers is 95%. For the peat CHP, the efficiencies are 68% (heat) and 17% (electricity). The distribution loss of 5% has been assumed to the centralized heating system.

Table 1 show cost information for each alternative. The annuity method has been applied to the investment cost. The annual specific cost is based on 10 years.

Table 1. Investment cost for different alternatives, MSEK/year

Alternative	Equip. cost	Culvert&heating center	Boilers M&M	Network M&M	Personal cost
Existing boilers update	0.98	0	0.5	0	1.3
Electric boiler center	0.68	1.52	0.3	0.1	1.3
Peat boiler center	2.55	1.52	1.2	0.1	2.0
Peat CHP center	5.54	1.52	1.2	0.1	2.5
BUV waste heat boiler center	1.54	1.52	0.3	0.1	1.3

Equip.: equipment; M&M: Management and maintenance cost; MSEK: million of Swedish Krona.

The fuel and electricity price used in the model is presented in Table 2, electricity certificate is also included if electricity is generated from the peat CHP. According to Bondesson (2008), an emission rights of 180 SEK/ton CO_2 has been allocated to oil and peat, which is presented in Table 2.

Table 2. Price, emission rights and emission factors of fuel and electricity

Fuel / electricity	Price, SEK/MWh	Emission rights, SEK/MWh	Emission factor, ton CO_2/MWh
Oil	370	54	0.3
El.	260	-	0
El. certificate	200	-	0
Peat	130	18	0.1

El.: electricity.

3. Modeling results

The modelling results include seven scenarios. They are: Scenario 1 - Reference case; Scenario 2 - Electric boiler center; Scenario 3 - Peat boiler center; Scenario 4 - Peat CHP center; Scenario 5 - BUV waste heat boiler center; Scenario 6 - Optimized reference case and Scenario 7 - Optimized case. Firstly the model is used to simulate the existing heating system and also four different technical alternatives, Scenario 1 to 5. Then the model has been run for two optimized case to find out the best option(s) among different alternatives and existing boilers (Scenario 7), and only among the existing boiler centers (Scenario 6) towards a lowest possible heat production cost.

The heat demand and supply for the reference case has been simulated in the model. The simulation results are in a good agreement with 2005 year's production data. Figure 1 (left) shows the heat supply from each boiler centre. Most heat is supplied from boiler centers of BUV, Vitåfors, Denevitz and Alliansen which are close to the mining sites so that the heat can be used for the mine ventilation. The heat supply sources are presented in Figure 1 (right). In this work, heat generated from compressors and waste heat boilers at pelletization plants of MK3 and BUV is called waste heat. In general, the existing heating system is an electricity based system, and oil boilers will be operated during some high heat load seasons. The curve also shows that some amount of waste heat has been utilized in the existing heat system, but only at Vitåfors and BUV boiler centers.

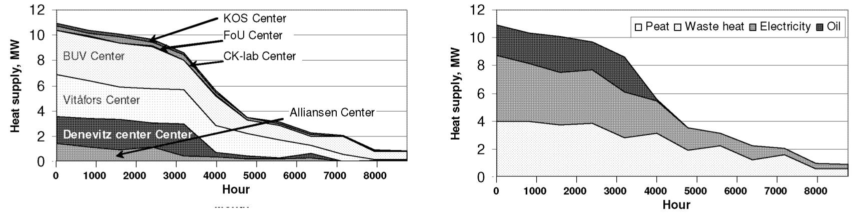

Figure 1. The duration curve of heat demand (left) and heat supply (right) in the reference case

Figure 2 (left) presents the heat supply curve for Scenario of the optimized case (Scenario 7). It has been found out that this scenario shows the same optimizing results as Scenario 5 - BUV waste heat boiler center. This indicates that Scenario 5 is the best option towards a lower heat production cost. In this scenario, the waste heat from flue gas at BUV pelletization plant will be recovered. The heat generated from the waste heat boiler will be delivered to other boiler centers through the heat network, and it has been prioritized to utilize during all seasons. However, during several high heat load periods, a small amount of heat has to be supplied from several existing electric boilers, which are newly installed at BUV center, Vitåfors center and KOS center to avoid extra investment to replace old electric boilers. Oil boilers have not been chosen due to a higher oil price compared to electricity.

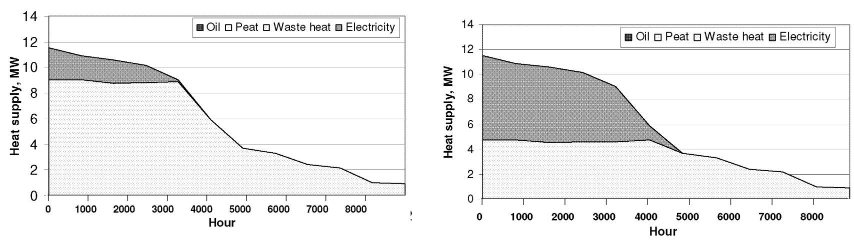

Figure 2. The duration curve of heat supply in the optimized case (left) and the optimized reference case (right)

When the existing boiler centers are connected in between by building up the culvert and a heat center, heat generated can be exchanged through the centralized heat network. Therefore, it is interesting to know what would happen when optimizing those existing boiler centers. Figure 2 (right) shows that oil boilers will not be used when optimizing the reference case. The waste heat generated from compressors at Vitåfors and BUV center will be delivered to other boiler centers. Which electric boilers will be operated depends on the heat demand load, and also if there is a need for some extra investment. It has been noticed that newly installed electric boilers are in operation during the high heat load periods. The heat generated from newly installed electric boilers, compressors and MK3 waste heat boiler can meet the heat demand at north side of LKAB Malmberget, and there is no need to invest new electric boilers.

4. Discussions

Figure 3 presents the total production cost for each scenario. Among all scenarios, BUV waste heat boiler center has the lowest heat production cost, which actually corresponds to Scenario of the optimized case. This is because that the waste heat (from compressors, MK3 and BUV waste heat boiler) has been effectively utilized in the centralized heat network, leading to a low fuel/electricity cost. Compared to the reference case, around 70% of electricity saving could be achieved in the optimized case. There will be no oil consumption in the optimized case, therefore, it can be predicted that a lower CO_2 and NO_x emission could be realized as well. By estimation, for instance, around 3000 ton CO_2 could be reduced with an emission factor of 0.3 ton CO_2/MWh oil, and NO_x emission reduction will be around 4.5 ton if an average NO_x emission factor of 0.45 kg NO_x/MWh oil is used.

Scenario of Peat CHP has the highest production cost due to higher investment cost even accounting 2.1 MSEK credits gained annually from the electricity production.

The optimized reference case scenario also shows a lower heat production cost. Different with the reference case scenario, it becomes a centralized heating network. Some waste heat, therefore, can be delivered to heat users located in other boiler centers, aiming to a lower production cost. The investment cost in this scenario includes building up a culvert system to link all existing boiler centers and a new heating system control center. It should be pointed out that a backup boiler system has been considered in this scenario to ensure a safer heating system at LKAB Malmberget.

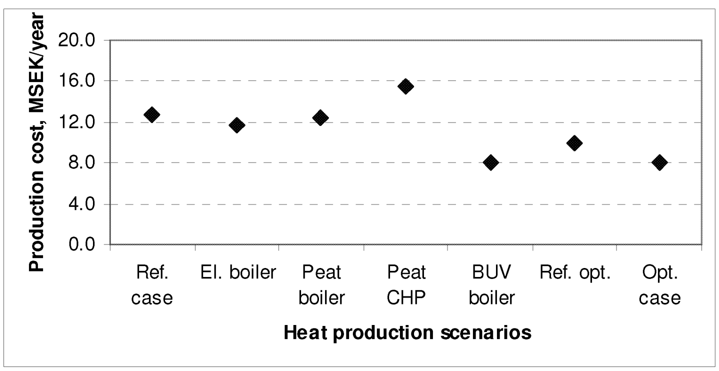

Figure 3. Total heat production cost annually for different scenarios

It has been noticed that in the optimized case scenario and the optimized reference case scenario, there is still some extra heat available from compressors, MK3 and BUV waste heat boilers during some months especially the summer season. This heat could be utilized when more heat users are linked to the heat network. The potential heat users are for example the local community.

It has also been noticed that the existing oil boilers, which are newly installed at centers of Aliansen and Denevita, will not be in use in the optimization cases. These boilers can be relocated to south part of LKAB Malmberget or used as back up boilers, leading to a lower cost for whole LKAB Malmberget heating system.

5. Conclusions

The following major conclusions could be drawn from this work:

- An optimization model has been created for DH system at LKAB Malmberget (North side). The model can be used to calculate how a given heat demand can be satisfied at the lowest possible cost;
- Modeling results indicate that a lower cost could be achieved if BUV waste heat boiler center (the optimized case) is built up, which will also lead to a remarkable electricity saving (around 70% saving) compared to the reference case; it has been noticed that in the optimized cases oil boilers will not be in operation due to a higher price compared to electricity, and by estimation this will lead to an annual reduction of 3000 ton CO_2 and 4.5 ton NO_x;
- It should be pointed out that a lower cost could also be achieved when a heat network is built up to link all the current existing boiler centers, i.e. when optimizing the reference case;
- In general, waste heats (e.g. from compressors, MK3 and BUV waste heat boiler) related to the pellet production system contribute to a lower total heat production cost for the centralized heating system;
- It has been noticed that during some periods, there is still some waste heat available for some external users.

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