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Carbon monoxide (CO) emissions from camping stoves

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English summary

Small commercially available camping stoves of four different brands (Optimus, MSR, Coleman and Sigg) were examined for carbon monoxide emission. Without a pot placed onto the stove the carbon monoxide production is very small (below 5 ml per min) which hardly represent any danger. The carbon monoxide production increased significantly for all the four brands (range from 20 to 140 ml CO per min) when the stoves were used for cooking i.e. when a pot of water was placed on the stove. This may represent a danger if the stoves are used within an enclosed area without adequate ventilation (e.g. in a tent). Our measurements give reason to warn especially against the brand Coleman.

Sammendrag

Små kommersielt tilgjengelige kokeapparat for friluftsliv fra fire produsenter (Optimus, MSR, Coleman, Sigg) er undersøkt vedrørende karbonmonoksyd (kullos) produksjon. Uten kjele på kokeapparatet er produksjonen av kullos svært lav (under 5 ml per min) og vil i mindre grad representere en fare. Produksjonen av kullos øker imidlertid betydelig for alle fire merkene når kokeapparatene benyttes til koking ved for eksempel at en kjele med vann plasseres på kokeapparatet (i området fra 20 til 140 ml CO per min). Dette kan representere en fare for kullos-forgiftning dersom kokeapparatet benyttes i et "avlukke" med mindre ventilasjon enn i friluft, for eksempel i et telt. Våre målinger gir grunn til spesielt å advare mot kokeapparat av merket Coleman.

Contents

Preface

This report is based on a Norwegian report, which has been published by Norwegian Defence Research Establishment (FFI) in 1997 (1). All the camping stoves tested in this report were purchased from stores in Oslo and Lillestrøm (Norway) in 1996-97. However, the camping stove Optimus 111 was delivered form the Norwegian Defence in the same period. The measurements used in this report have also been done in the same period. Most of the tests are done by FFI, but some have been done by SINTEF in Trondheim (2).

Mrs. Jennifer C. Chisholm-Høibråten has translated the report from Norwegian to English.

1 Introduction

The Norwegian Armed Forces utilise a large number of small Primus camping stoves (Optimus 111) to heat small cotton tents (3-6 person) and for the preparation of food and drink. There has been very little study of harmful emissions from such camping stoves. However, the camping stoves utilised by the Armed Forces have been tried out over a long period of time without any reports of problems involving harmful emissions.

With the continual introduction to the civilian market of new models of camping stoves for outdoor life, and as more and more of these gain entry to the Norwegian outdoor life milieu, there is an increasing possibility that these civilian camping stoves will be used in the Armed Forces. Even with the Armed Forces' restrictive attitude with regards to permitting the use of civilian equipment, the possibility that civilian camping stoves may be used in the field cannot be excluded. These might be camping stoves that were never intended to be utilised in the manner that the Armed Forces makes use of its camping stoves today.

Another aspect is that personnel from other NATO countries who are training in Norway bring along their own equipment, including their own camping stoves. These forces are often in contact with Norwegian soldiers and in some instances, the visiting forces are instructed or supervised by Norwegian military personnel, especially in connection with tackling Norwegian winter conditions. The possibility that Norwegian practices when using the Norwegian Armed Forces Primus camping stoves, will be followed by other countries and influence the way they use their own camping stoves. However, the equipment used by other countries may not have been used in this manner before. The Optimus Primus camping stove comes to mind, which in the Norwegian Army is used for cooking and heating inside small tents. These are uses that could be dangerous when other kinds of camping stoves are used in a similar manner.

With this background in mind, the Norwegian Defence Research Establishment (FFI) has detected a need to study emissions from the most commonly used civilian camping stoves. Of the gas emissions that these stoves give off, carbon monoxide (CO) represents the greatest danger. Our study therefore concentrates exclusively on this extremely poisonous gas that is both odourless and without flavour.

Since the results of this study could affect commercial interests, we have endeavoured to have our measurements checked against independently carried out measurements. Hence FFI commissioned the Division of Thermal Energy and Hydroelectric Power at SINTEF Energy to carry out independent measurements of the emissions. This report reproduces both the SINTEF measurements as well as our own so that consistency in the results of the measurements may be judged.

2 The gas carbon monoxide (CO)

Carbon monoxide is created along with carbon dioxide (CO_2) during the combustion of all organic material and hydrocarbons such as petroleum, paraffin and heptane. As a rule, the generation of carbon monoxide is extremely small, but in the event of incomplete combustion where the availability of oxygen is limited, the generation of carbon monoxide will increase dramatically.

Carbon monoxide is an extremely poisonous gas that has led to numerous deaths. The toxicity of the gas is caused by carbon monoxide molecules that attaches themselves to the haemoglobin in the blood and displaces the oxygen due to an affinity that is over 200 times greater. Because of this high affinity, even a concentration of 0.4 mm Hg, that is to say about 500 ppm (parts per million) in the lungs would lead to a progressive binding of CO to the haemoglobin (Ganong 2005) (3). When 70 to 80% of the blood's haemoglobin is bonded to CO, death will ensue. This occurs not only as a result of the dramatic reduction of the blood's capacity to transport oxygen in such a case, but also because the carbon monoxide reduces the haemoglobin's ability to release oxygen in the cellular tissue, that is the oxygen that already exists in the blood.

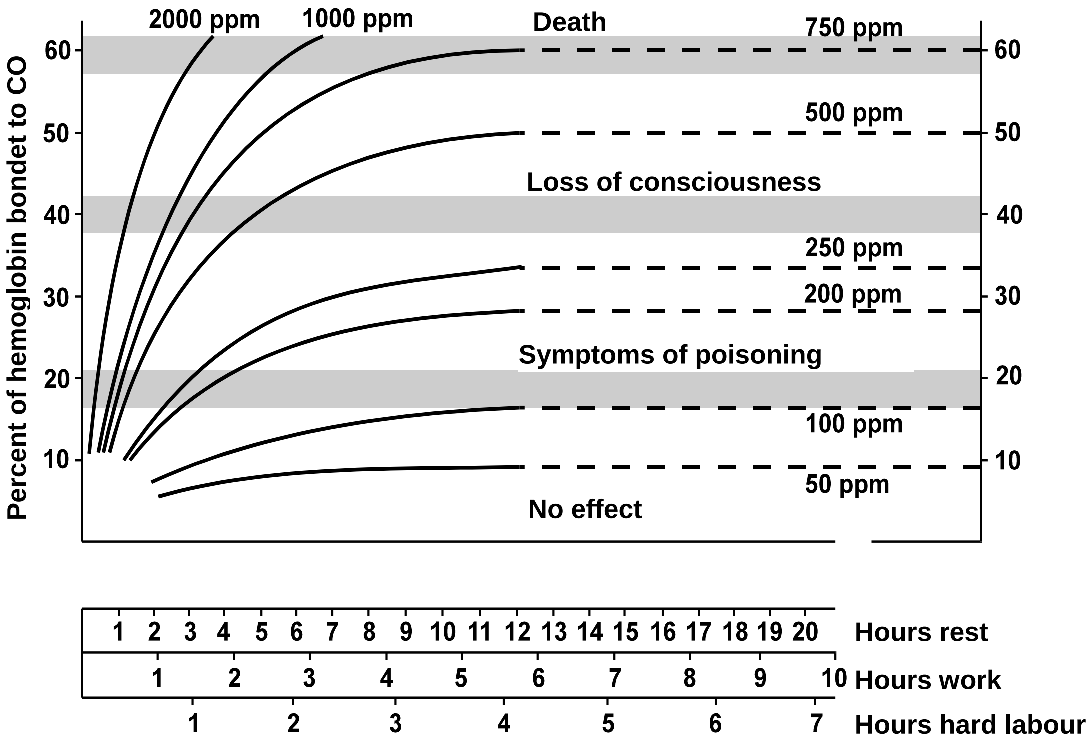

Figure 2.1 Human reaction to carbon monoxide (CO) is determined by the relative amount of haemoglobin that is bonded to CO. The haemoglobin's uptake of CO in the blood in turn depends on the concentration (given in ppm over the 8 curves in the diagram), the duration of exposure, and the work load. Data furnished by Dräger Information, 21 Ausgabe.

The uptake of CO however depends on the concentration, duration of the exposure and the person's lung ventilation, that is, the work load of the particular individual during the time of exposure. Figure 2.1 illustrates this connection and shows the conditions in which loss of consciousness and symptoms of poisoning will occur.

A visible symptom of carbon monoxide poisoning is that the skins under the nails and on the mucous membranes become cherry red in colour. This is due to a change of colour in the haemoglobin when it binds to the CO in the blood. It is only when the degree of poisoning is very serious that this colour change becomes visible.

Other symptoms of carbon monoxide poisoning are of the same character as oxygen deficiency (hypoxia), that is to say headaches and a feeling of nausea. However, the breathing apparatus is little stimulated by a lack of oxygen owing to CO poisoning. The reason for this is that the blood's partial pressure for oxygen in the arteries remains normal whereby the chemoreceptors in the carotid and aortic body are not stimulated.

The few and weak symptoms of carbon monoxide poisoning combined with the fact that carbon monoxide gas is odourless and has neither colour or flavour, mean that the gas is difficult to detect and is thereby extremely dangerous.

3 Carbon monoxide (CO) emissions from camping stoves

Experiments were carried out on four different brands of camping stove that operated on the pressure burner principle. The idea of this principle is that the fuel is put under pressure in a tank equipped with a manual pumping system. In this way, fuel in the form of gas is well mixed with air. This mixing takes place when the fuel is pressed through an opening in a nozzle by means of an overpressure of about 1 bar. The result is a fairly clean combustion while simultaneously achieving a high effect. The pressure-burner apparatuses are constructed such that either paraffin or a gasoline-like fuel may be used. Some apparatuses can utilise both types of fuel, in which case the nozzle should be changed or other changes made prior to using the different fuel. These "multi-fuel" apparatuses are often primarily constructed for one of the fuel types. The camping stoves presented here in which both fuel types can be used, are primarily constructed for fuels having qualities similar to gasoline. Heptane is an example of such a fuel and is one of the fuels used in our experiments. In the remaining experiments involving pressure burners, we have used paraffin.

Most of the measurements were made at FFI. The measurements carried out at SINTEF utilised approximately the same method as FFI. A more detailed description of the SINTEF method and results may be found in the SINTEF report by Karlsvik (1997) (2).

3.1 Measurements carried out with and without a pot

The experiments used camping stoves made by four different manufacturers (Optimus, MSR, Coleman and Sigg). The measurements showed that when the camping stove is standing and burning without any pot over the flame, the emission of CO will be quite small. With a pot however, a marked increase in the camping stove's emission of CO may be observed. The reason for this is that the flame cools upon meeting a surface, in this case the bottom of a cold pot, and the chemical processes are altered. The result is an increased production of CO.

Figure 3.1 illustrates this state. Without the pot, the development of carbon monoxide from all four models of camping stove was quite low – less than 5 ml a minute. With a pot however, the development of carbon monoxide increased dramatically, and with the Coleman brand, it increased by a factor of 200. In the ensuing discussion, only experiments in which the cooker is used with a pot will be presented.

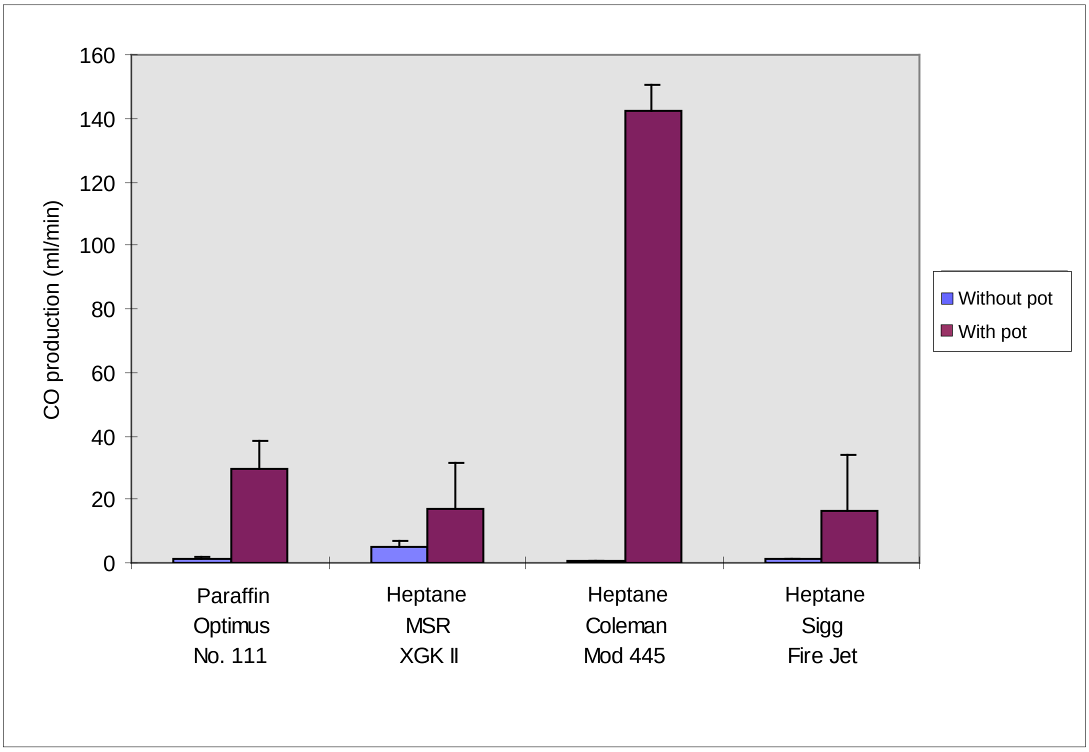

Figure 3.1 Formation of carbon monoxide (CO) for four different cookers, both with and without a pot. The average value with its associated standard deviation is shown. The Norwegian Defence Research Establishment carried out two to five measurements on each of the brands at a power level of 2.0 ± 0.6 kW (average value with standard deviation). The four different brands of camping stoves represented in the tests are, starting from the left, Optimus, MSR, Coleman and Sigg. The Optimus model only utilises paraffin for fuel.

3.2 Measurements carried out by two research institutes

Measurements of emissions were carried out by both FFI and SINTEF in which the same models of camping stove were used. The comparative results of the two research institutes when carrying out experiments on the four brands of camping stoves *with* the use of a pot are shown in Figure 3.2. The measurements show excellent agreement between the results from the two research institutes SINTEF and FFI.

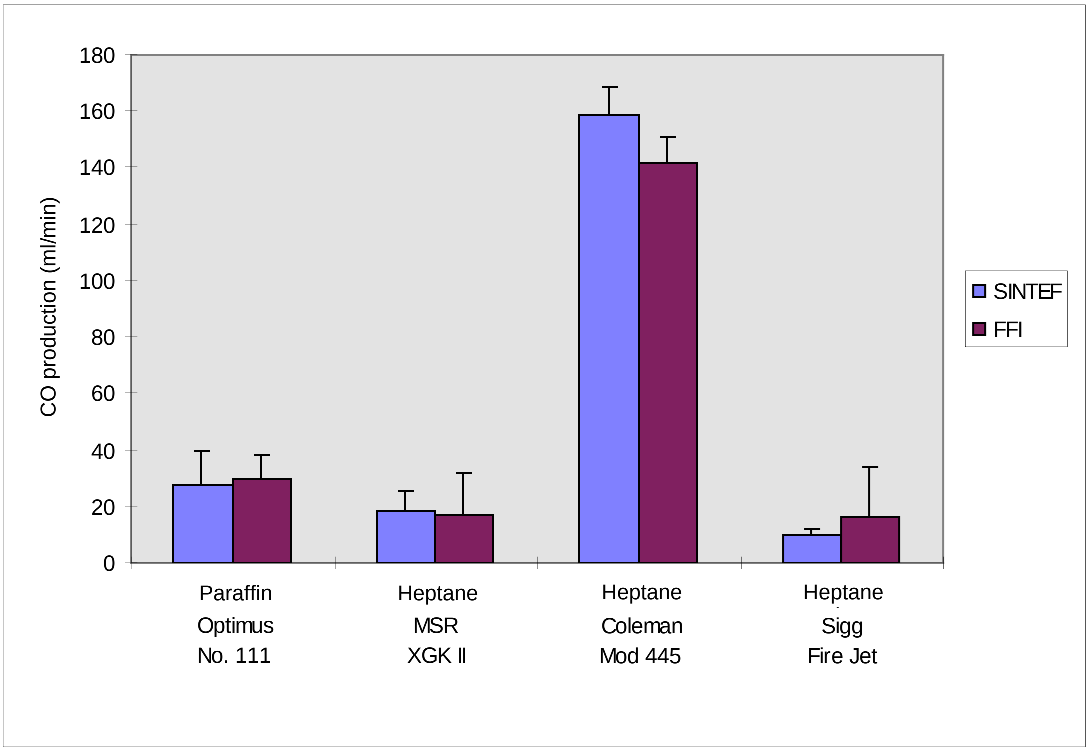

Figure 3.2 Formation of carbon monoxide (CO) for four different camping stoves using a pot. The average value with its associated standard deviation is shown. The measurements were made by SINTEF Energy and the Norwegian Defence Research Establishment (FFI), who carried out four to five measurements, and two to five measurements respectively at a power level of 2.3 ± 0.7 and 2.0 ± 0.6 kW respectively (average value with standard deviation). The four different camping stoves represented are from the left Optimus, MSR, Coleman and Sigg. The Optimus models can only use paraffin for fuel.

3.3 Significance of power level for production of carbon monoxide in the four brands

3.3.1 Optimus camping stoves

Forty six experiments were carried out on 11 different camping stoves of the Optimus brand. Most of these experiments (35) were carried out on the Optimus 11 model which is the type used in the Norwegian Armed Forces, but the "Optimus Explorer", "Optimus 111C Hiker" and "Optimus Ranger" were also examined.

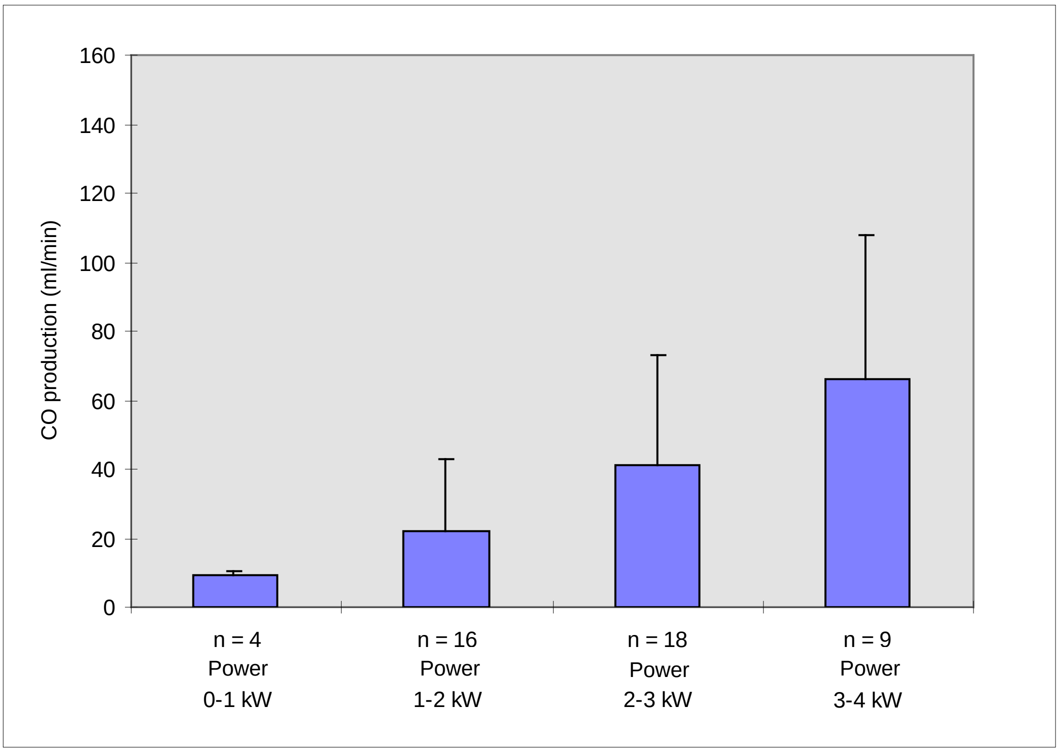

Figure 3.3 Formation of carbon monoxide at four different power spans for Optimus brand camping stoves using a pot. The average value with associated standard deviation and the number of experiments (n) are shown. Measurements carried out by SINTEF Energy (n=12) and the Norwegian Defence Research Establishment (FFI) (n=34).

Figure 3.3 shows that the production of carbon monoxide is relatively low when the cooker is burning at low power levels, but increases when the power increases. However, power levels over 3 kW can be difficult to achieve. The maximum effect depends on the pressure in the fuel tank which is increased by a hand pump, and there are limits for how much the pressure in the tank can be increased with this pump. Experiments at power levels over 3 kW, reproduced here, were carried out with pressure from a compressed air system connected to the fuel tank.

3.3.2 MSR camping stoves

Twenty two experiments were carried out on five camping stoves representing the MSR brand. The experiments were spread between the two models “XGK II” and “Wisperlite 600” with 14 and 8 experiments respectively.

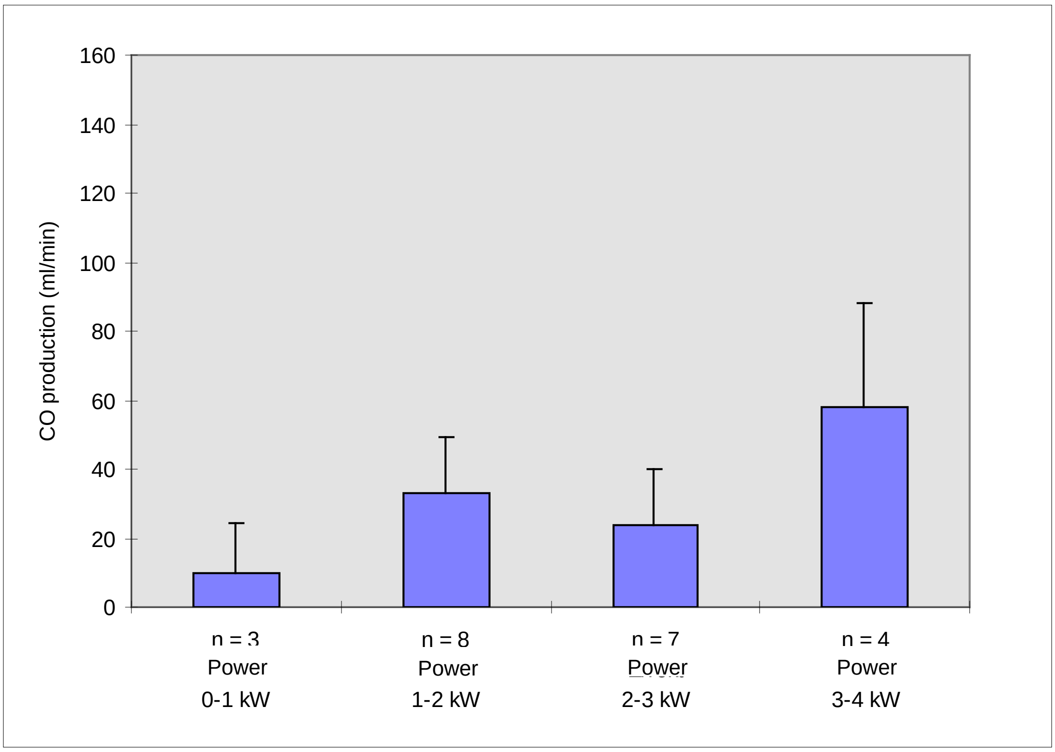

Figure 3.4 Formation of carbon monoxide (CO) at four different power spans for MSR camping stoves using a pot. The average value with associated standard deviation and the number of experiments (n) are shown. Measurements carried out by SINTEF Energy (n=10) and the Norwegian Defence Research Establishment (n=12).

Figure 3.4 shows that the production of carbon monoxide is relatively low in this model, even at power levels up to 3 kW. At power levels above this value however, there is some increase in the production of carbon monoxide, but these are relatively unrealistic values for the same reasons mentioned in point 3.3.1.

3.3.3 Coleman camping stoves

Thirty six experiments were carried out on six different camping stoves of the Coleman brand. The experiments were spread out between three models “Mod.445-Apex II”, “Mod. 442-Feather” and “Mod.550-Multifuel” with 17, 16 and 3 experiments carried out on the models respectively.

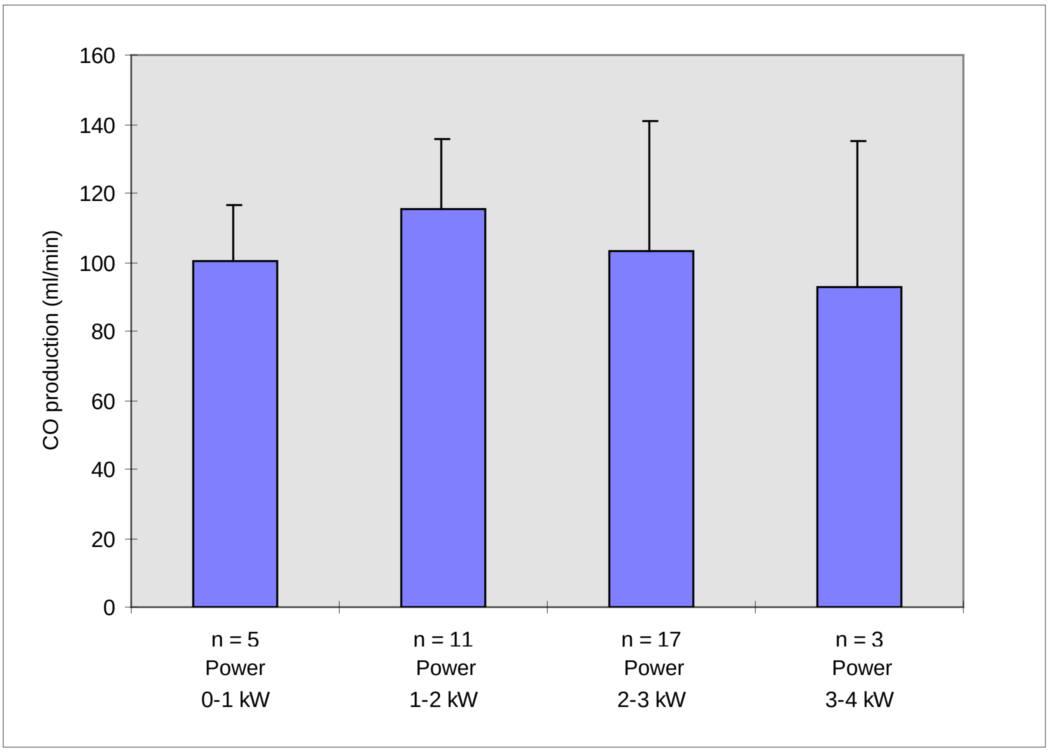

Figure 3.5 Formation of carbon monoxide (CO) at four different power spans for Coleman camping stoves using a pot. The average value with associated standard deviation and the number of experiments (n) are shown. Measurements carried out by SINTEF Energy (n=8) and the Norwegian Defence Research Institute (n=28).

Figure 3.5 shows that the production of carbon monoxide is high at all power levels, including at low power. This tendency is not observed in the other brands, where the production of carbon monoxide diminishes with decreasing power levels.

3.3.4 Sigg camping stoves

Seven experiments were carried out on the “Fire Jet” camping stove manufactured by Sigg. Figure 3.6 shows low levels of carbon monoxide for this model. No experiments were carried out at power levels above 2 kW because the cooker is designed for a maximum power of 1.5 kW.

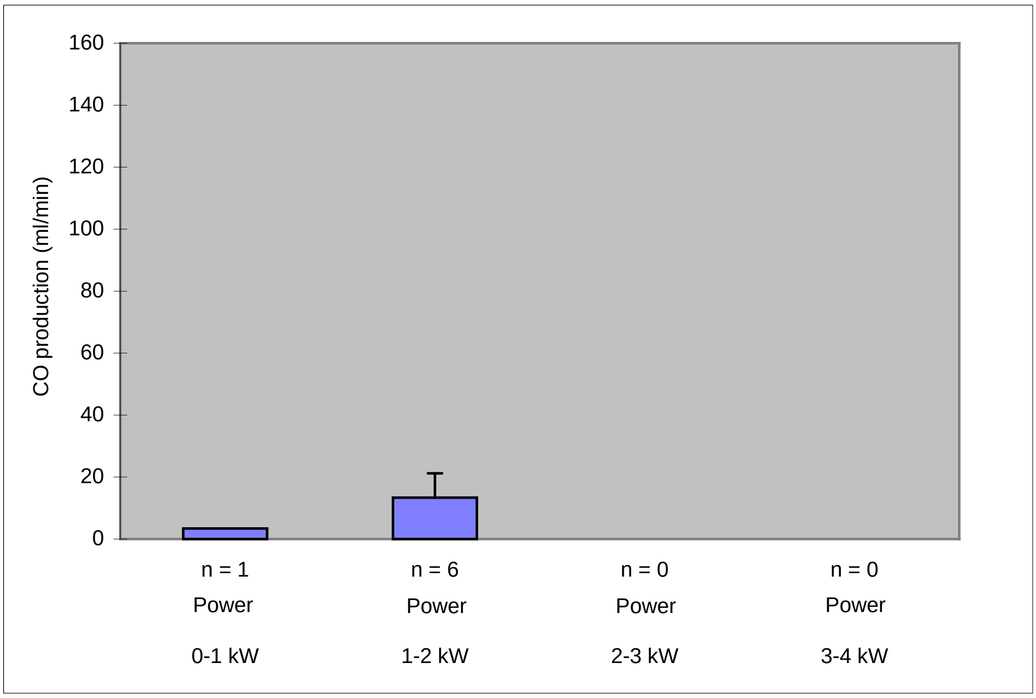

Figure 3.6 Formation of carbon monoxide (CO) at two different power spans for the Sigg camping stove using a pot. The maximum power level for this design is 1.5 kW; therefore no values appear for the higher power levels. The average value with associated standard deviation and the number of experiments (n) are shown. Measurements carried out by SINTEF Energy (n=5) and the Norwegian Defence Research Establishment (n=2).

4 Assessment of risk of carbon monoxide poisoning

Whether or not there is any danger of carbon monoxide poisoning for a person depends on the concentration the individual has been exposed to, the duration of time he or she has been exposed, and the work load the individual had at the time of exposure. This connection is illustrated in Figure 2.1.

With respect to the maximum limit for acute exposure, Wabeke (1996) (4) refers to a value of 1500 ppm, which is the recommended limit stated by the National Institute for Occupational Safety and Health in the United States. At such high concentrations of carbon monoxide, this agency considered that there was immediate danger to life and health.

In its directive “Administrative standards for atmospheric contamination of the workplace”, The Norwegian Directorate of Labour Inspection set a limit for CO at 25 ppm (5). This is to say that the average concentration of CO in the course of an eight hour work day or shift is recommended to lie below 25 ppm. The directive states furthermore that short term exposure to the gas should not exceed 100 ppm. If there is a risk of this occurring, written instructions are to be developed for working in a CO atmosphere.

4.1 Information provided by the manufacturer/importer about carbon monoxide

In the user's guide for Coleman camping stoves, it is stated in the safety instructions that the stove is "for outdoors use only", and furthermore that "the stove consumes air (oxygen) and should only be used in well ventilated places". The same user's guide also states that "Refuelling and lighting the stove should always be done outside (outside of the tent). The last sentence could however be interpreted to mean that the stove can nonetheless be used inside the tent so long as it is lit outside.

The user's guide for the MSR brand gives similar information: "Do not use stove without adequate ventilation. Liquid fuel stoves produce hazardous by-products of combustion and will consume available oxygen within an enclosed area." The gas carbon monoxide (CO) however is not mentioned in the user's guide in either of these two brands.

Under the heading "Safety" in the user's guide for the Optimus brand of camping stoves, the following is stated (although not until point 8): "Never use the camping stove indoors (i.e. inside a tent) in that open flame can cause fires and the risk of carbon monoxide."

This shows that the manufacturer has secured itself against the risk of carbon monoxide poisoning by informing the user that the stove must only be used outside. The question is whether more specific information could be provided about the risk of carbon monoxide. Furthermore, the wording is ambiguous in that it remains unclear whether the term "outdoors use" includes use in a tent or not, especially with respect to the user's guide for the Coleman brand of camping stoves.

4.2 Use of camping stoves in tents

In open air, the production of carbon monoxide from camping stoves will not be a problem. If the camping stove is used in a form of small room or booth where ventilation is limited, the concentration of carbon monoxide that a person nearby is exposed to, will increase. Therefore these camping stoves should not be used indoors. The user's guide for the different camping stoves also warns against this where it is pointed out that the camping stoves must be used outdoors. As mentioned earlier, it is unclear whether the term "outdoors" also comprises use of the stoves inside a tent, although some of the user's guides do indeed warn against use inside a tent. However it remains a fact that many of these camping stoves are used in tents, both for cooking and as a source of heat. The Norwegian Armed Forces have long used their Primus (Optimus) stoves as a means of heating tents without any reports of problems with emissions.

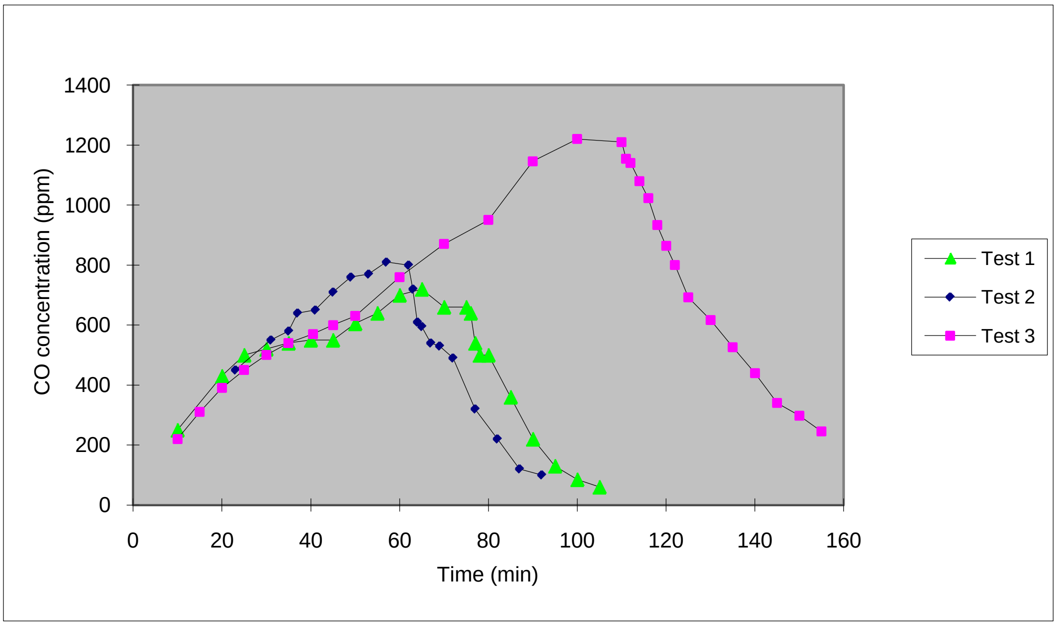

Figure 4.1 Build-up and ventilation of carbon monoxide in tents during use of camping stoves with a pot. Tests 1, 2 and 3 were done outdoors at FFI, with the stoves shut off after 60, 70 and 100 minutes respectively. For this series of experiments, a model 445 Coleman camping stove was used at a power level of 1–2 kW.

The concentration of carbon monoxide in a tent will depend upon the extent of ventilation and the amount of carbon monoxide emissions the camping stove gives off. In a tent, the degree of ventilation can vary a lot depending on the weather conditions, where and how the tent has been erected, the construction of the tent and which of the tent's ventilation possibilities are being used. Wind and precipitation will affect the ventilation, as for example when supercooled rain coats the outside of the tent like a form of ice armouring such that the tent becomes quite airtight. This will reduce the ventilation in the tent.

Three experiments were carried out outdoors at FFI in which a Coleman camping stove with a pot on top was put on to burn at a power of 1-2 kW inside a tent. An ordinary 3-person field tent with a waterproof outer layer of polyurethane-covered nylon was used. Figure 4.1 illustrates the increase in the concentration of carbon monoxide approximately 1 meter away from the stove in the closed tent. There was snow around the tent, very little wind (>3m/s) and the temperature lay between –2 to +4 °C.

The high concentrations of carbon monoxide that were measured in these conditions give cause for concern. Furthermore, on the basis of simultaneous measurements of CO_2, we can establish that the production of carbon monoxide increases after about 40 minutes. We do not know why this increase occurs, but it causes extra high concentrations of carbon monoxide inside the tent. In test 3, the power level of the camping stove dropped after about 60 minutes. This, however, did not stop the concentration of CO from rising even further.

It should be pointed out that in this particular case, the openings of the tent were closed, but the air vents were open. Besides, the camping stove was placed inside the inner tent and not in the outer tent which is usually used in such cases. Furthermore there was snow lying around the tent so that there were no openings between the outer tent and the ground. All of these factors combined with the weather conditions contributed to reducing ventilation in the tent. However, the experimental conditions are realistic.

4.3 Camping stoves at low power levels

It seems unlikely that the camping stoves under study here and that are used for hiking trips will be used at high power levels for longer periods of time. The reason for this is the difficulty of maintaining pressure in the tank. The pressure must be maintained by manually pumping up the tank frequently. Additionally, there is a great likelihood of the nozzle becoming sooty when the stove is kept burning for long periods of time. Furthermore, the contents of the pot will relatively quickly either begin to boil or else burn, which would seldom go unnoticed by anyone in the near vicinity. Therefore, the risk of these camping stoves being left to burn with a pot atop the burner for a long time at high power is relatively small.

If for example a camping stove is left unattended, the power will probably diminish as the pressure in the tank decreases. In this way, the camping stove could stay burning at a low power level for a long time before it is discovered. In view of this, it is worrying that Coleman brand camping stoves produce so much CO at low power levels.

5 Conclusion

If camping stoves are to be used exclusively for heating purposes i.e., that no items will be placed on the stove burner whereby the flame is cooled down, the emission of carbon monoxide will be very small. It is only when something is placed on the camping stove burner that the production of carbon monoxide will assume a level that must be taken into account. However, we cannot ignore the fact that there are also other conditions besides placing a cold cooking pot on top of the camping stove that can lead to a correspondingly large increase in the creation of carbon monoxide.

In open air, the production of carbon monoxide will not be a problem. On the other hand, carbon monoxide can become a problem in small enclosed areas with less ventilation than in the open air, as for example in a tent. For most of the camping stoves, it is stated that they should only be used outdoors, and in the case of certain individual models, it is warned not to use them inside, as for example in a tent. Our measurements give reason to warn against the use of camping stoves for cooking inside tents lacking good ventilation. It is particularly advised against cooking over longer periods of time. Consequently, the use of camping stoves inside tents for time consuming efforts such as ice and snow melting in large pots should be avoided.

The results of this study suggest a need for particular caution when using camping stoves of the Coleman brand (Models 445 and 442) in tents or similarly enclosed spaces under otherwise standard conditions. What particularly sets the Coleman brand apart from the others is that the production of carbon monoxide does not decrease when the power decreases; on the contrary, it appears that it will at times even increase (cf. Figure 4.1). When using Coleman camping stoves at low power levels (0-1 kW), the production of CO lies at a level that is about 10 times higher than that of the other brands.

The Norwegian Armed Forces should be aware that the practices when using their Primus stoves in tents, may be adopted by other nations through the co-operation with NATO, and may also transfer to civilian outdoors life through soldiers doing their military service. Hence there may be some risk of harm with these practices, if other kinds of camping stoves are utilised in a similar manner.

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